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FUZE GEAR TRAIN EFFICIENCY

G. G. LOWEN
CITY COLLEGE OF NEW YORK
NEW YORK, NEW YORK

F. R. TEPPER
ARRADCOM

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INTRODUCTION

The point efficiencies of various types of fuze related step-up gear trains were investigated and insights concerning the reasons for the resulting differences in these efficiencies are provided. The investigation also represents an application and extension of the tools furnished in Fuze Gear Train Analysis (FGTA) (ref 1).

The FGTA report (ref 1) deals primarily with the derivation of expressions and their subsequent computer formulation for point and cycle efficiencies of two and three pass step-up gear trains, with involute or clock gear teeth, which must operate in a spin environment. These programs are easily modified to simulate nonspin environments. In addition, derivations and computer programs are given for efficiency analyses of single pass involute and clock gear meshes which operate in nonspin environments. The report also contains a program for the design of the unity contact ratio involute meshes having unequal addenda, which were used in the study.

The present report gives the results of the efficiency comparisons between involute and clock gear two and three pass step-up gear trains which operate in spin and nonspin environments.

To perform these comparisons and to make their results as meaningful as possible, a number of preliminary tasks had to be carried out. Since no American standard for the design of clock tooth gear and pinion sets could be found, a computer program was written which uses British Standard No. 978 (ref 2). The three pass step-up gear trains were modeled after the M125A1 (brass) safety and arming device, and since no comparable two pass step-up train was initially available a two pass train with essentially the same step-up ratio was designed.

In order to simulate the randomness of the gear train assembly and to start the simulations with the worst possible starting conditions, the initialization parameters J_1 have been introduced into the programs. These parameters make it possible to start the motion of any mesh anywhere between 0% and 100% of the total angle from earliest to latest tooth contact in a single tooth cycle of the driving gear. The worst starting condition for an involute mesh occurs at the start of approach action, i.e., when J_1 equals zero. For a clock gear mesh it occurs at the end of the recess action when J_1 equals unity.

To learn more concerning the geometrical factors which influence the point efficiencies of multipass step-up gear trains, additional analyses pertaining to compound gears and single pass meshes with involute and clock type teeth were performed. It was found that the distance of the line of action of the resultant force of the driving gear on the driven pinion from the friction circle, associated with the pinion pivot, is an important indicator of efficiency in step-up meshes. This distance, which depends on a number of parameters in addition to pivot radius and coefficient of friction, may be used as an optimization criterion in future work.

SUMMARY

Friction Circle and Efficiency of Single Gear and Pinion Combination

The concept of the friction circle was reviewed and related to the efficiency of a compound gear and pinion. The resulting expression, associated with this simple model in which the input force acts on the pinion while the equilibrating output force acts on the gear, indicated that the input-output efficiency is a function of the distance of the line of action of the input force from the friction circle. The larger this distance, the greater becomes this efficiency. Locking will occur if this distance becomes zero or the line of action passes inside the friction circle.

Efficiency Comparison Between Involute and Clock Gear Type Single Pass Step-up Gear Trains

Computer comparison of point efficiencies for increasingly severe friction conditions between involute and clock gear single pass step-up gear trains are presented here. Subsequently, analytical expressions for the distance of the line of action of the resultant force of the gear on the pinion from the pinion axis are given for both types of gearing and discussed. (The distance to the pinion axis, rather than the one to the friction circle was chosen for simplicity.)

Comparing the point efficiencies of the two types of gear trains revealed:

1. Regardless of the magnitude of the coefficient of friction, the point efficiency at initial contact, i.e., at the earliest possible position during approach action, is always higher for the clock gear mesh than for the involute mesh. This effect becomes especially pronounced for higher values of the coefficient of friction, when the involute mesh indicates a tendency to lock. This result may explain the greater tolerance of clock tooth trains when foreign material is unintentionally present.
2. The maximum point efficiencies of both types of meshes are essentially the same for a given coefficient of friction and occur at or near the pitch point.
3. The efficiencies of both types of meshes decrease during recess action with the greater decrease taking place in the clock gear configuration.
4. As a consequence of the above, the worst starting condition, i.e., the greatest danger of stalling due to a limited input moment and a high coefficient of friction, is associated with the beginning of approach action for involute meshes and the end for recess action for clock gear meshes.

The following conclusions were obtained from work performed concerning the distance of the line of action of the resultant force of the gear on the pinion from the pinion axis in involute meshes:

1. An increase of the coefficient of friction causes a decrease in this distance, becoming especially pronounced at initial contact if the approach angle is large.

2. The distance is generally smaller during approach action than during recess action.

3. An increase in the step-up ratio of a mesh in which the pinion remains the same causes a small decrease in the distance.

4. When the pitch radius of the pinion is large, this distance becomes larger.

5. An increase in the pressure angle of a given mesh decreases this distance from the line of action of the force to the pinion axis.

Comparing clock gear and involute meshes relative to the line of action of the force of the gear on the pinion from the pinion axis revealed:

1. Just as the point efficiency at initial contact is higher for the clock gear meshes than for involute meshes, regardless of the magnitude of the coefficient of friction, the distance is always larger for clock meshes at that instant. This difference in magnitude becomes more pronounced as the coefficient of friction increases.

2. The increase of the distance as approach action progresses is smaller for comparable clock meshes than for involute meshes. At the pitch point, the distance is essentially the same for both types of configurations. During recess, this distance decreases more for clock meshes than for involute meshes because the approach angle is larger in involute meshes while the reverse is true for the recess angle.

There is a proportional relationship between the distance of the line of action from the pinion axis and the point efficiency for any given contact condition, and, therefore, any geometrical change which increases this distance will also increase the point efficiency.

Since the point efficiency of involute meshes is only undesirable at the very beginning of the approach action, any modification which decreases contact before the pitch point, while maintaining an acceptable contact ratio, may produce gear meshes with generally higher point efficiencies than are found in clock gear meshes.

Efficiency Comparisons Between Involute and Clock Two and Three Pass Step-up Gear Trains in Spin and Nonspin Environments

The two pass trains were designed to have the same step-up ratio as the three pass trains and the newly introduced initialization parameters were used to obtain the worst possible starting conditions for all individual meshes.

The comparisons led to the following conclusions:

1. For a given mesh and spin condition there is no significant difference in the range of point efficiencies between involute and clock gears.
2. Without spin the two pass step-up trains are more efficient than the three pass trains.
3. With spin the three pass meshes are slightly more efficient than the two pass meshes.
4. All mesh point efficiencies are independent of the magnitude of the spin velocity.

Revision of Program INVOL3

A revised version, as well as an updated description of program INVOL3 which allows the determination of point and cycle efficiencies for three pass involute tooth step-up gear trains operating in a spin environment is given in appendix A. (All meshes have unity contact ratio.)

The original program was listed and described in detail in appendix C-3 of reference 1.

The present version of the program contains three initialization parameters J_1 which allow the initial point of contact of each of the three meshes to be chosen arbitrarily. Further, for convenience and appropriate checking, certain gear and fuze parameters have been made part of the data and/or the output of the program. The data used in the new sample program are identical to those of the original sample program in reference 1. In order to obtain the worst starting conditions for an involute train, the three initialization parameters were set equal to zero in the sample program.

Revision of Program INVOL4

A revised version, as well as an updated description of program INVOL4 which allows the determination of point and cycle efficiencies for two pass involute tooth step-up gear trains operating in a spin environment is given in appendix B. (All meshes have unity contact ratio.)

The original program was listed and described in detail in appendix C-4 of reference 1.

The present version of the program contains two initialization parameters J_1 which allow the initial point of contact of each of the two meshes to be chosen arbitrarily. Further, for reasons of convenience, and to allow appropriate checking, certain gear and fuze parameters have been made part of the data and/or the output of the program.

The data used in the new sample program differ from those used in reference 1. A new gear train, which has essentially the same step-up ratio as the three pass train, was designed. The gear parameters associated with this train were obtained with the help of program INVOL1 (originally given in appendix C-1, reference 1). The output of this program, one for each of the two meshes, is listed in appendix B. In order to obtain the worst possible starting conditions for an involute train, the two initialization parameters were set equal to zero in the sample program.

Design of Clock Tooth Gear and Pinion Set According to British Standard No. 978

Program BRITSTD for the design of clock tooth gear and pinion sets, according to British Standard No. 978 (ref 2), is given in appendix C. This program furnishes all necessary input parameters (i.e., gear and pinion dimensions) for programs CLOCK1 and CLOCK2, which are both listed in appendix F of reference 1, as well as the revised programs CLOCK3 and CLOCK4, which are given in appendixes D and E, respectively, of the present report.

The appendix also shows how to determine the center of curvature coordinates of the addendum radius of clock teeth with data from the standard. The associated computer program is listed in the appendix. In addition, five sample outputs are given. These furnish the input data for the sample runs of the revised programs CLOCK3 and CLOCK4.

Revision of Program CLOCK3

A revised version, as well as an updated description, of program CLOCK3, which allows the determination of point and cycle efficiencies for three pass clock tooth step-up trains operating in a spin environment is given in appendix D.

The original program was listed and described in appendix I-1 of reference 1.

The present version of the program contains three initialization parameters J_1 which allow the initial point of contact of each of the three meshes to be chosen arbitrarily. Certain gear and pinion parameters have been added to the

input as well as to the output of the program. The data used in the sample program are identical to those in reference 1 with respect to diametral pitch and number of teeth of the individual meshes. The specific tooth dimensions were obtained with the help of program BRITSTD. (See first three sets of outputs in appendix C.) In order to approximate the worst starting conditions for a clock tooth train, the three initialization parameters were set equal to 0.9 in the sample program.

Revision of Program CLOCK4

A revised version, as well as an updated description, of program CLOCK4, which allows the determination of point and cycle efficiencies of two pass clock tooth step-up gear trains operating in a spin environment is given in appendix E.

The original program was listed and described in appendix I-2 of reference 1.

The present version of the program contains two initialization parameters J_1 which allow the initial point of contact of each of the two meshes to be chosen arbitrarily. Certain gear and pinion parameters have been added to the input as well as to the output of the program.

The data used in the new sample program differ from those used in reference 1. The new clock tooth train has the same step-up ratio, gear and pinion tooth numbers, and diametral pitches as were given to the new involute tooth two pass train (appendix B of the present report). The specific tooth dimensions were obtained with the help of program BRITSTD (fourth and fifth output sets in appendix C). In order to approximate the worst starting conditions for a clock tooth train, the two initialization parameters were set equal to 0.9 in the sample program.

FRICTION CIRCLE AND EFFICIENCY OF SINGLE GEAR AND PINION COMBINATION

Friction Circle

A free-body diagram of a single gear and pinion combination is shown in Figure 1. The common pivot shaft has the radius ρ . This compound gear is driven in a clockwise direction by the input force F_1 which acts on the pinion portion of the combination at distance a from the pivot axis O . Force F_0 , at distance b from the pivot axis, is exerted by the next component of the gear train on the gear portion of the combination. The pivot bearing applies the reaction R on the pivot shaft. It consists of the normal component N and the tangential friction force component μN (where μ represents the coefficient of friction between pivot shaft and bearing). Since the friction force must oppose rotation, the vector sum

$$\vec{R} = \vec{N} + \vec{\mu N} \quad (1)$$

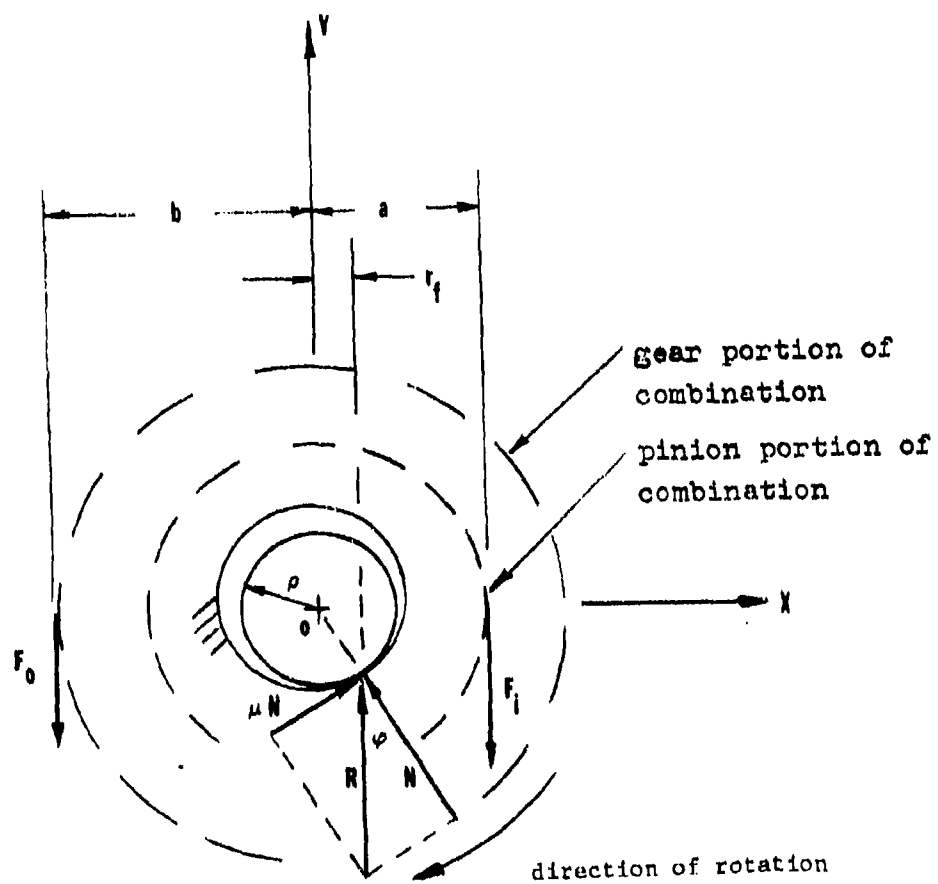


Figure 1. Free-body diagram of single gear and pinion combination

can only be satisfied if the line of action of force R is located at the right hand side of the pivot center O. Varignon's theorem is used to determine the distance r_f of this line of action from the pivot axis. This theorem states that the moment of a force with respect to an axis equals the sum of the moments of the components of this force with respect to the same axis. Taking moments with respect to point O, one obtains for the forces R and μN :

$$r_f R = \mu N \quad (2)$$

(Note that the normal component N exerts no moment about point O.) With

$$N = R \cos \phi, \text{ and} \quad (3)$$

$$\mu = \tan \phi \quad (4)$$

one obtains from equation 2,

$$r_f = \rho \sin \phi \quad (5)$$

This distance r_f represents the radius of the so-called friction circle and regardless of its direction, the bearing reaction R will always be tangent to this circle.

Efficiency of Single Gear and Pinion Combination

While figure 1 represents a simplified description of the loading condition of a single gear and pinion combination, since forces F_1 and F_0 are parallel, one may still obtain valuable insights concerning efficiency and locking from it.

To obtain the relationship between forces F_0 and F_1 , the following force and moment equilibrium conditions are used:

$$\sum F_y = 0: -F_1 - F_0 + R = 0 \quad (6)$$

$$\sum M_O = 0: bF_0 - aF_1 + r_f R = 0 \quad (7)$$

The moment equation 7 may be rewritten with the help of equation 6.

$$bF_0 - aF_1 + r_f(F_1 + F_0) = 0 \quad (8)$$

The above furnishes the following expression for the output force F_0 .

$$F_0 = F_1 \left(\frac{a - r_f}{b + r_f} \right) \quad (9)$$

Equation 9 may now be used to devise an efficiency expression. Assume that the combination gear rotates through a clockwise angle $\Delta\theta$.

The work done by force F_1 is given by

$$W_1 = F_1 a \Delta\theta \quad (10)$$

The work of force F_0 becomes for the same rotation

$$W_0 = -F_1 b \Delta\theta \left(\frac{a - r_f}{b + r_f} \right) \quad (11)$$

The efficiency η may now be found from the ratio of the output to the input work. Thus,

$$\eta = \left| \frac{W_0}{W_1} \right| = \frac{1 - \frac{r_f}{a}}{1 + \frac{r_f}{b}} \quad (12)$$

The following conclusions concerning the efficiency of single gear and pinion combinations are drawn from equation 12:

1. The friction circle radius r_f should be as small as possible.
2. The distance b should be as large as possible. This generally offers no difficulty in step-up gear trains since force F_0 is applied to the gear portion of the combination which has a relatively large pitch radius.
3. Most importantly, the distance a should be as large as possible. This condition is critical in step-up gear trains since force F_1 acts on the pinion portion of the combination and the associated distance a is never very large.

Equation 12 shows that friction locking may occur when $a \leq r_f$, i.e., when the line of action of the force on the pinion passes either tangent to or inside of the friction circle.

EFFICIENCY COMPARISONS BETWEEN INVOLUTE AND CLOCK GEAR TYPE SINGLE PASS STEP-UP GEAR TRAINS

To make the conclusions of the comparisons more general, the influence of the position of the line of action of the force of the gear on the pinion, with respect to the pinion pivot, on the mesh efficiencies is discussed for both types of gearing.

Efficiencies of Single Pass Step-up Gear Meshes with Involute and Clock Gear Type Teeth

Point efficiency comparisons between similar involute and clock gear type meshes are given in table 1. The involute mesh was designed with the help of computer program INVOL1 (ref 1). The efficiency computations for the involute mesh were obtained from computer program INVOL2 (ref 1). Computer program BRITSTD, which is listed and discussed in appendix C forms the basis of the design of the clock gear train. The efficiency computations of this single step-up mesh were made with computer program CLOCK2 (ref 1).

Both types of meshes have the following data in common:

- P_d = 44, diametral pitch
- N_G = 48, number of teeth of gear
- N_P = 8, number of teeth of pinion
- ρ_N = 0.060 in. (0.152 cm), pivot radius of gear (also subscript 1)
- ρ_n = 0.030 in. (0.076 cm), pivot radius of pinion (also subscript 2)

The coefficient of friction is varied from $\mu = 0.1$ to $\mu = 0.8$.

The specific data for the involute mesh, as designed by INVOL1 to have unequal addenda and unity contact ratio, are as follows:

- θ = 20° the pressure angle
- R_p = 0.54545 in. (1.3854 cm) r_p = 0.09091 in. (0.2309 cm) (pitch radii)
- R_b = 0.51256 in. (1.3019 cm) r_b = 0.08543 in. (0.2170 cm) (base circle radii)
- R_o = 0.55609 in. (1.4125 cm) r_o = 0.10985 in. (0.2790 cm) (outside radii)

The specific data for the clock gear mesh, as obtained with the help of program BRITSTD, are given by:

- R_p = 0.54545 in. (1.3854 cm) r_p = 0.09091 in. (0.2309 cm) (pitch radii)
- a_G = 0.54157 in. (1.3756 cm) a_p = 0.09083 in. (0.2307 cm) (positions of centers of curvature)

Table 1. Comparison of single pass step-up gear efficiencies as functions of coefficient of friction with nonzero pivot radii. (Obtained with programs INVOL2 and CLOCK2)

Coeffi- cient of friction (μ)	Clock tooth shape efficiency			Involute tooth shape efficiency		
	Initial contact point (ϵ_p)	Maximum point (ϵ_p)	Final contact point (ϵ_p)	Initial contact point (ϵ_p)	Maximum point (ϵ_p)	Final contact point (ϵ_p)
0.1	0.933	0.956	0.883	0.900	0.954	0.919
0.2	0.866	0.913	0.785	0.796	0.912	0.846
0.3	0.800	0.872	0.700	0.688	0.874	0.781
0.4	0.734	0.833	0.626	0.576	0.834	0.721
0.5	0.668	0.796	0.562	0.460	0.806	0.666
0.6	0.602	0.760	0.505	0.340	0.776	0.615
0.7	0.536	0.726	0.455	0.214	0.748	0.568
0.8	0.471	0.693	0.409	0.084	0.722	0.525

$\rho_G = 0.04886$ in. (0.1241 cm) $\rho_P = 0.01591$ in. (0.0404 cm) (radii of tooth curvature)

$t_G = 0.03608$ in. (0.0916 cm) $t_P = 0.02382$ in. (0.0605 cm) (tooth thicknesses at pitch circles)

Similar efficiency comparisons for the same meshes are given in table 2. To illustrate the effects of tooth contact friction only, the pivot radii ρ_N and ρ_n were made equal to zero.

Both tables show maximum point efficiencies and point efficiencies for the earliest possible contact of the meshes (at the maximum angles of approach), as well as for the final contact, when a new set of teeth is about to come into engagement.

The data for tables 1 and 2 are derived from the typical outputs of program INVOL2 and CLOCK2 which are shown in tables 3 and 4, respectively.

Conclusions of Efficiency Comparisons

Inspection of table 1 permits the following conclusions:

1. Regardless of the magnitude of the coefficient of friction, the point efficiency e_p at initial, i.e., earliest possible, contact is always higher for the clock gear mesh than for the involute mesh. This effect becomes especially pronounced for higher values of the coefficient of friction, when the involute mesh indicates a tendency to lock. This result may explain the greater tolerance of clock tooth type trains for the presence of foreign material during assembly.

2. Both involute and clock gear point efficiencies increase steadily after initial contact has been made and until maximum point efficiency is reached. The rate of increase of efficiency is much greater for the involute mesh (tables 3 and 4).

3. The maximum point efficiencies of both mesh types are essentially the same for a given coefficient of friction. They occur when the contact point between gear and pinion coincides with the line connecting their pivots. Since in this position there is no relative velocity between the contacting surfaces of the teeth, there is also no friction force.

4. The efficiencies of both mesh types decrease steadily after the maximum has been reached at pitch point contact. The rate of this decrease is much less pronounced for the involute mesh. The latest possible contact efficiency of the involute mesh is higher than that of the clock gear (table 1). Therefore, if one can design a modified involute step-up mesh which avoids contact before the pitch point as much as possible and still has an acceptable contact ratio, it may show higher efficiencies than a comparable clock gear mesh.

Table 2. Comparison of single pass step-up gear efficiencies as functions of coefficient of friction with zero pivot radii. (Obtained with programs INVOL2 and CLOCK2)

Coeffi- cient of friction (μ)	Clock tooth shape efficiency			Involute tooth shape efficiency		
	Initial contact point (ϵ_p)	Maximum point (ϵ_p)	Final contact point (ϵ_p)	Initial contact point (ϵ_p)	Maximum point (ϵ_p)	Final contact point (ϵ_p)
0.1	0.977	1.000	0.929	0.947	0.999	0.964
0.2	0.954	0.999	0.867	0.890	0.999	0.930
0.3	0.930	0.998	0.812	0.830	0.998	0.899
0.4	0.906	0.998	0.765	0.765	0.998	0.870
0.5	0.881	0.997	0.722	0.697	0.997	0.843
0.6	0.856	0.997	0.684	0.623	0.996	0.818
0.7	0.831	0.996	0.650	0.545	0.995	0.795
0.8	0.804	0.996	0.619	0.460	0.994	0.773

Table 3. Typical output of program INVOL2 for table 2

GEAR PITCH RADIUS (CAPPR) = .54545 PINION PITCH RADIUS (RPI) = .09091
 GEAR OUTSIDE RADIUS (CAPO) = .55609 PINION OUTSIDE RADIUS FOR UNITY CONTACT RATIO (ROFIN) = .10985
 PRESSURE ANGLE IN DEGREES (THETAD) = 20.00
 GEAR PIVOT RADIUS (RHOCAPN) = .060 PINION PIVOT RADIUS (RHON) = .030
 COEFFICIENT OF FRICTION (MU) = .10
 RANGE DIVISOR (K) = 50

ALPHAD = 16.61	S = 1.0	POINTEF = .8996
ALPHAD = 16.76	S = 1.0	POINTEF = .9014
ALPHAD = 16.91	S = 1.0	POINTEF = .9031
ALPHAD = 17.06	S = 1.0	POINTEF = .9051
ALPHAD = 17.21	S = 1.0	POINTEF = .9070
ALPHAD = 17.36	S = 1.0	POINTEF = .9088
ALPHAD = 17.51	S = 1.0	POINTEF = .9106
ALPHAD = 17.66	S = 1.0	POINTEF = .9125
ALPHAD = 17.81	S = 1.0	POINTEF = .9143
ALPHAD = 17.96	S = 1.0	POINTEF = .9162
ALPHAD = 18.11	S = 1.0	POINTEF = .9180
ALPHAD = 18.26	S = 1.0	POINTEF = .9199
ALPHAD = 18.41	S = 1.0	POINTEF = .9217
ALPHAD = 18.56	S = 1.0	POINTEF = .9236
ALPHAD = 18.71	S = 1.0	POINTEF = .9254
ALPHAD = 18.86	S = 1.0	POINTEF = .9273
ALPHAD = 19.01	S = 1.0	POINTEF = .9291
ALPHAD = 19.16	S = 1.0	POINTEF = .9310
ALPHAD = 19.31	S = 1.0	POINTEF = .9328
ALPHAD = 19.46	S = 1.0	POINTEF = .9347
ALPHAD = 19.61	S = 1.0	POINTEF = .9366
ALPHAD = 19.76	S = 1.0	POINTEF = .9384
ALPHAD = 19.91	S = 1.0	POINTEF = .9403
ALPHAD = 20.06	S = 1.0	POINTEF = .9421
ALPHAD = 20.21	S = 1.0	POINTEF = .9440
ALPHAD = 20.36	S = 1.0	POINTEF = .9459
ALPHAD = 20.51	S = 1.0	POINTEF = .9477
ALPHAD = 20.66	S = 1.0	POINTEF = .9496
ALPHAD = 20.81	S = 1.0	POINTEF = .9515
ALPHAD = 20.96	S = 1.0	POINTEF = .9541
ALPHAD = 21.11	S = 1.0	POINTEF = .9524
ALPHAD = 21.26	S = 1.0	POINTEF = .9506
ALPHAD = 21.41	S = 1.0	POINTEF = .9489
ALPHAD = 21.56	S = 1.0	POINTEF = .9471
ALPHAD = 21.71	S = 1.0	POINTEF = .9454
ALPHAD = 21.86	S = 1.0	POINTEF = .9437
ALPHAD = 22.01	S = 1.0	POINTEF = .9420
ALPHAD = 22.16	S = 1.0	POINTEF = .9402
ALPHAD = 22.31	S = 1.0	POINTEF = .9385
ALPHAD = 22.46	S = 1.0	POINTEF = .9368
ALPHAD = 22.61	S = 1.0	POINTEF = .9350
ALPHAD = 22.76	S = 1.0	POINTEF = .9333
ALPHAD = 22.91	S = 1.0	POINTEF = .9316
ALPHAD = 23.06	S = 1.0	POINTEF = .9299
ALPHAD = 23.21	S = 1.0	POINTEF = .9281
ALPHAD = 23.36	S = 1.0	POINTEF = .9264
ALPHAD = 23.51	S = 1.0	POINTEF = .9247
ALPHAD = 23.66	S = 1.0	POINTEF = .9230
ALPHAD = 23.81	S = 1.0	POINTEF = .9212
ALPHAD = 23.96	S = 1.0	POINTEF = .9195

Table 4. Typical output of program CLOCK2 for table 2

[illegible]

The results of efficiency computations for involute and clock gear meshes with zero pivot radii (table 2) show the same general tendencies as were found for the configurations of table 1. In addition, it confirms the well-known rule of making the pivot radii as small as possible in order to assure high point efficiencies.

Position of Line of Action of Force of Gear on Pinion in Involute and Clock Gear Meshes

The section on efficiency of single gear and pinion combination showed that to avoid locking and to improve the efficiency of a single compound gear and pinion it is desirable to have the line of action of the input force pass as far as possible from the friction circle and with that from the pivot of the pinion. The following provides some insights concerning the position of this line of action in involute and clock gear meshes during the various phases of contact. It is intended to serve as a starting point for future work on mesh efficiency improvement.

Position of Line of Action of Force of Gear on Pinion in an Involute Mesh

The force of the gear on the pinion, together with the associated line of action, as it appears during both approach and recess, is shown in figure 2. F_a represents the contact force during approach and F_r is the same force during recess. As indicated in the figure, the direction of the friction force component μF is reversed as contact changes from approach to recess. It is to be recalled that this is due to a similar change in the direction of the relative velocity between the gear and pinion contact points. Since the relative velocity is zero when contact occurs at the pitch point, the friction component also vanishes at that instant. (For a discussion of the above concepts see appendix A-1 (ref 1). The normal component F of the contact force retains its direction throughout the complete cycle of motion.

The distance of the line of action of the resultant force from the pinion pivot O_n is smaller during most of the approach motion than it is during recess motion (fig. 2). The symbols r_{Ma} and r_{Mr} are used for this distance during approach and recess, respectively, while r_{Mp} is used for pitch point contact. The following gives analytical expressions for these terms and discusses possible ways of maximizing them:

1. Distance r_{Ma} During Approach Motion

The distance of the line of action from point O_n may be determined with the help of Varignon's theorem, i.e., the sum of the moments of the forces F and μF with respect to point O_n equals the moment of the resultant F_a with respect to the same point. Thus, vectorially

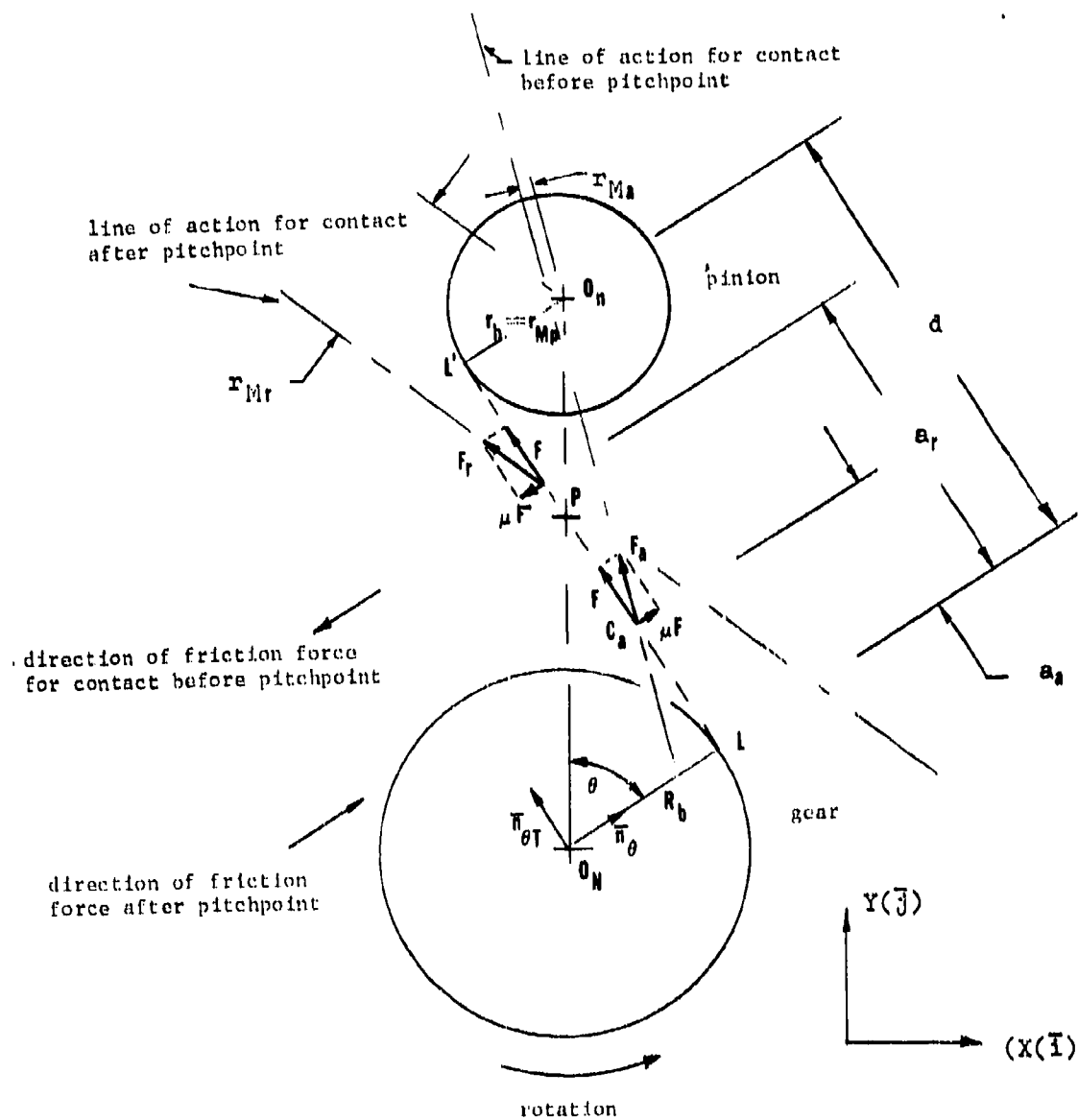


Figure 2. Line of action of force of gear on pinion
In an involute step-up mesh

$$\vec{r}_{Ma} \times \vec{F}_a = [-r_b \vec{n}_\theta + (d - a_a)(-\vec{n}_{\theta T})] \times [F \vec{n}_{\theta T} + \mu F \vec{n}_\theta] \quad (13)$$

where

μ = coefficient of friction between teeth

F_a = resultant force during approach, equal to $F \sqrt{1 + \mu^2}$

F = normal component of resultant force

μF = friction component of resultant force

r_b = pinion base radius

d = distance $\overline{LL'}$ (fig. 2)

a_a = distance from point L to gear and pinion contact point C_a during approach. ($a_a < LP$)

$$\left. \begin{aligned} \vec{n}_\theta &= \sin \theta \vec{i} + \cos \theta \vec{j} \\ \vec{n}_{\theta T} &= -\cos \theta \vec{i} + \sin \theta \vec{j} \end{aligned} \right\}^1$$

When equation 13 is solved for the moment arm r_{Ma} , which represents the perpendicular distance from the line of action to point O_n , one obtains the following scalar quantity:

$$r_{Ma} = \frac{r_b - \mu(d - a_a)}{\sqrt{1 + \mu^2}} \quad (14)$$

For greater insight the above expression is rewritten with the help of

$r_b = r_p \cos \theta$, where r_p is the pinion pitch radius

$d = (R_p + r_p) \sin \theta$, where R_p is the gear pitch radius

$a_a = K_a R_p \sin \theta$, where $K_a = \overline{C_a L} / LP < 1$ since the length $\overline{C_a L}$ is less than the distance LP . The closer the contact of gear and pinion to point L along line LP, the smaller is K_a

¹See equations A-4 and A-5 of reference 1 for these unit vectors. θ is the pressure angle.

Thus, one obtains for equation 14

$$r_{Ma} = \frac{r_p}{\sqrt{1 + \mu^2}} \left\{ \cos \theta - \mu \sin \theta \left[1 + \frac{R_p}{r_p} (1 - K_a) \right] \right\} \quad (15)$$

2. Distance r_{Mp} for Contact at the Pitchpoint

Since there is no friction component when contact takes place at the pitch point, the distance r_M becomes

$$r_{Mp} = r_b = r_p \cos \theta \quad (16)$$

3. Distance r_{Mr} During Recess Motion

For contact during recess, the sign of the friction component $\mu \bar{F} \bar{n}_\theta$ in equation 13 must be reversed. Also since contact is now made after the pitch point, the distance from point L to the contact point (not specifically called out in fig. 2) becomes

$$a_r = K_r R_p \sin \theta$$

where

$$K_r > 1$$

The resulting scalar expression has the form

$$r_{Mr} = \frac{r_p}{\sqrt{1 + \mu^2}} \left\{ \cos \theta - \mu \sin \theta \left[\frac{R_p}{r_p} (K_r - 1) - 1 \right] \right\} \quad (17)$$

If the above is expressed similar to equation 14, it becomes

$$r_{Mr} = \frac{r_b + \mu (d - a_r)}{\sqrt{1 + \mu^2}} \quad (18)$$

4. Conclusions for Involute Meshes

Equations 15 through 17 and the data in tables 5 and 6 were used to draw the following conclusions concerning the distance r_M of the line of action of the resultant force of the gear on the pinion from the pinion pivot:²

For All Contact Conditions.

1. The larger the pitch radius of the pinion, the larger becomes the distance r_M and with that the less becomes the danger of locking or of obtaining excessively low efficiencies according to equation 12. (Note that the symbol r_M now replaces the symbol a in this expression. Further, it must be understood that equations 15 and 17 are not valid for contact at the pitch point.)

2. With the exception of a short distance, at the beginning of recess motion, an increase of the coefficient of friction decreases the distance r_M . (Compare columns III and IV of table 5.)

3. For otherwise fixed conditions an increase in the step-up ratio R_p/r_p generally causes a small decrease in the distance r_M .

4. For equal distances along the line LL' before and after the pitch point (fig. 2), i.e., for $K_a = 1 - x$ and $K_r = 1 + x$, the distance r_M is always smaller for the approach case. (Compare values for $K_a = 0.8$ and $K_r = 1.2$ in all columns of table 5. Similar information is contained in all rows of table 6.)

5. For otherwise fixed conditions, the distance r_M decreases as the pressure angle is increased (table 6).

For Contact During Approach. For any given configuration, the factor K_a should be as close to unity as possible in order to avoid excessively small values of r_{Ma} . This implies that initial contact between the gear and the pinion should be near the pitch point, i.e., the angle of approach should be small.

It is to be noted that r_{Ma} is always less than r_b which represents its value at the pitch point (equation 16 and columns III, IV and V of table 5).

For Contact During Recess. For any set of fixed conditions the maximum value of r_M is reached shortly after the pitch point is passed. This maximum value of r_{Mr} is larger than the associated distance r_{Mp} at the pitch point. This maximum

²The distance from the pinion friction circle gives direct information concerning the possibility of locking. Any conclusions concerning mesh efficiency must also take the distance of this line of action from the gear pivot into account.

Table 5. Distance r_M of line action from pinion axis
according to equations 15 through 17
[for pressure angle $\theta = 20^\circ$]

I	II	III	IV	V
Approach factor K_a	Recess factor K_r	Distances r_{Ma}, r_{Mp}, r_{Mr} for $\mu = 0.1$ $R_p/r_p = 6$	Distances r_{Ma}, r_{Mp}, r_{Mr} for $\mu = 0.3$ $R_p/r_p = 6$	Distances r_{Ma}, r_{Mp}, r_{Mr} for $\mu = 0.1$ $R_p/r_p = 8$
0.4	-	0.778 r_p	0.448 r_p	0.737 r_p
0.6	-	0.819	0.566	0.792
0.8	-	0.860	0.684	0.846
0.9	-	0.880	0.749	0.873
0.95	-	0.891	0.772	0.887
Pitch point	-	0.934 $r_p = r_b$	0.934 r_p	0.934 r_p
-	1.001	0.968	0.997	0.969
-	1.01	0.966	0.993	0.966
-	1.10	0.949	0.939	0.942
-	1.20	0.928	0.880	0.914
-	1.40	0.880	0.762	0.860

Table 6. Influence of pressure angle on distance r_M according to equations 15 through 17 [for $\mu = 0.1$, $R_p/r_p = 6$]

Pressure angle θ (degrees)	Approach distance r_{Ma} ($K_a = 0.9$)	Pitch point distance r_{Mp}	Recess distance r_{Mr} ($K_r = 1.1$)
14	$0.927 r_p$	$0.970 r_p$	$0.975 r_p$
16	0.913	0.961	0.967
18	0.897	0.951	0.958
20	0.880	0.940	0.948
22	0.863	0.927	0.937
24	0.844	0.913	0.925

value increases with an increase in the coefficient of friction (conclusion no. 2 above).

Position of Line of Action of Force of Gear on Pinion in a Clock Gear Mesh

Distance r_{Mrd} for Round on Round Phase of the Motion

The normal force F of the gear on the pinion, together with the friction force μF for a typical contact condition during the round on round phase of the motion is shown in figure 3. While the normal force always has the direction of the unit vector $\bar{n}_\lambda$, the direction of the friction force depends on the direction of the relative velocity $\bar{V}_{S/T}$ between the contact point S of the gear and the contact point T of the pinion (fig. 3). Equation E-50 (ref 1) shows that the sense of this friction force may be obtained with the signum function $s_R = V_{S/T}/|V_{S/T}|$. The friction force with a positive s_R is shown in figure 3.

Varignon's theorem was used to determine the distance r_{Mrd} of the line of action of the resultant force F_{rd} from the pinion pivot O_n , i.e.,

$$\bar{r}_{Mrd} \times \bar{F}_{rd} = (a_p \bar{n}_p - \rho_p \bar{n}_\lambda) \times (F \bar{n}_\lambda + \mu s_R F \bar{n}_{N\lambda}) \quad (19)$$

where

$$F_{rd} = F \sqrt{1 + \mu^2}$$

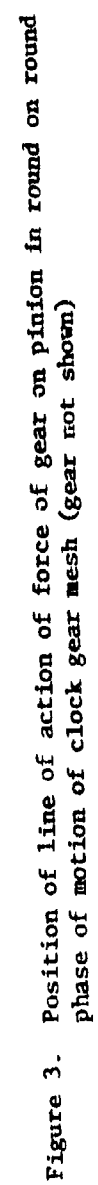
a_p = $O_n C_p$, the distance from the pivot to the center of curvature of the pinion profile

ρ_p = radius of curvature of pinion profile

$\bar{n}_p$ = $\cos(\psi - \delta_p) \bar{i} + \sin(\psi - \delta_p) \bar{j}$,
see equation E-4 (ref 1)

$\bar{n}_\lambda$ = $\cos \lambda \bar{i} + \sin \lambda \bar{j}$, see equation E-2 (ref 1)

$\bar{n}_{N\lambda}$ = $-\sin \lambda \bar{i} + \cos \lambda \bar{j}$, see equation E-3 (ref 1)



When equation 19 is solved for the absolute value of the moment arm r_{Mrd} , one obtains

$$r_{Mrd} = \frac{1}{\sqrt{1 + \mu^2}} \{ a_p [\sin(\lambda - \psi + \delta_p) + \mu a_R \cos(\lambda - \psi + \delta_p)] - \mu a_R \rho_p \} \quad (20)$$

Distance r_{Mf} for Round on Flat Phase of the Motion

The normal force F of the gear on the pinion, together with the associated friction force μF for a typical contact condition during the round on flat phase of the motion is shown in figure 4. This contact is made at point T of the radial pinion flank which is at a distance g from the pinion pivot O_n . The normal force always has the negative direction of the unit vector $\bar{n}_{NP}$ (equation E-22, ref 1), while the friction force has the direction of the unit vector $\bar{n}_F$ (eq E-23, ref 1) at all times.

Since friction force, μF , does not exert a moment about the pivot point, O_n , the moment of the resultant force, F_f , at the distance r_{Mf} , must be equal to the moment of force F at the distance g . Thus,

$$\bar{r}_{Mf} \times \bar{F}_f = g \bar{n}_F \times F(-\bar{n}_{NP}) \quad (21)$$

where, again

$$F_f = F \sqrt{1 + \mu^2}$$

When equation 21 is solved for the absolute value of the moment arm r_{Mf} , one obtains

$$r_{Mf} = \frac{g}{\sqrt{1 + \mu^2}} \quad (22)$$

Distance r_{Mp} for Contact on the Line of Centers (Pitch Point)

When contact points S and T coincide with the line of centers, i.e., the line connecting the gear and pinion pivots, the relative velocity $\bar{V}_{S/T}$ vanishes as it changes directions. The clock gear computer programs indicate the passing of the contact points through the line of centers by a change of sign of the signum parameter. Such a change of sign of the parameter s_R between the angles $\phi = 178.0813^\circ$ and $\phi = 178.2313^\circ$ while the mesh is in the round on round phase of the motion is shown in table 4. Since all presently examined clock gear

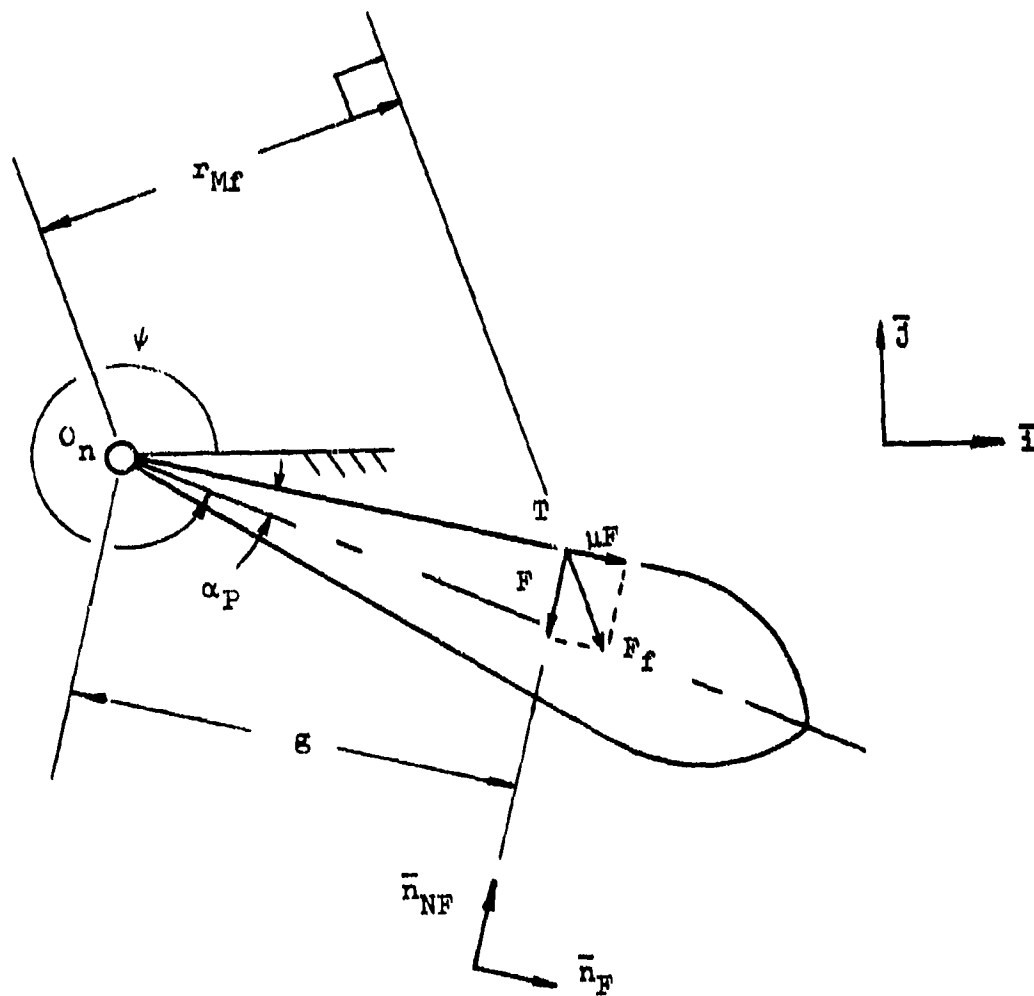


Figure 4. Position of line of action of force of gear on pinion in round on flat phase of motion of clock gear mesh

meshes show centerline contact during the round on round phase of motion, the derivation for the distance of the line of action from the pinion pivot must use the round on round parameters of equations 19 and 20.

With $\bar{V}_{S/T} = 0$, the friction component μF vanishes and the normal force F becomes the resultant force of the gear on the pinion (fig. 3). The normal distance r_{Mp} of force F from the pinion pivot may be obtained by setting $\mu = 0$ in equation 20. This furnishes

$$r_{Mp} = a_p \sin (\lambda - \psi + \delta_p) \quad (23)$$

As previously, the absolute value of r_{Mp} is desired.

Comparison of Line of Action Distances r_M for Clock and Involute Type Meshes

Comparison of the distances of the lines of action of resultant forces of the gear on the pinion from the pinion pivots for comparable clock gear and involute type meshes which operate with coefficients of friction of 0.1 and 0.8 is shown in table 7.

The gear and pinion sets are those described in the section on single pass step-up gear meshes with involute and clock gear type teeth and which form the bases of tables 3 and 4. Both have a diametral pitch of 44 and the numbers of the teeth of the gears and the pinions are 48 and 8, respectively.

The computations for the involute gear mesh are based on equations 14, 16, and 18. Specific parameters for the evaluation of these expressions are as follows:

$$r_b = r_p \cos \theta = 0.09091 \cos 20 = 0.08543 \text{ in. (0.2170 cm)}$$

$$\begin{aligned} d &= (R_b + r_b) \tan \theta = (0.51255 + 0.08543) \tan 20 \\ &= 0.21764 \text{ in. (0.5528 cm)} \end{aligned}$$

The distances a_a and a_r are computed with the help of equation A-203 (ref 1), i.e.,

$$a_a, a_r = R_b \alpha \quad (24)$$

Table 7 Comparison of line of action distances
 r_M for clock gear and involute meshes

Contact angle (deg)	Distance r_M for $\mu = 0.1$				Distance r_M for $\mu = 0.8$			
	Clock mesh		Involute mesh		Clock mesh		Involute mesh	
	In. (cm)	Eq no.	In. (cm)	Eq no.	In. (cm)	Eq no.	In. (cm)	Eq no.
0.00	0.0864 (0.2195)	20	0.0781 (0.1984)	14	0.0523 (0.1328)	20	0.0235 (0.0597)	14
0.90	0.0883 (0.2243)	20	0.0789 (0.2004)	14	0.0589 (0.1496)	20	0.0286 (0.0726)	14
1.80	0.0891 (0.2263)	20	0.0797 (0.2024)	14	0.0640 (0.1626)	20	0.0336 (0.0853)	14
1.80	Pitch point 0.0907 (0.2304)	23	(*)		Pitch point 0.0907 (0.2304)	23	(*)	
1.95	0.0911 (0.2313)	20	0.0798 (0.2029)	14	0.0768 (0.1951)	20	0.0334 (0.0848)	14
3.30	0.0889 (0.2259)	20	0.0810 (0.2057)	14	0.0700 (0.1778)	20	0.0420 (0.1067)	14
3.45	0.0885 (0.2248)	22	0.0812 (0.2062)	14	0.0694 (0.1763)	22	0.0428 (0.1087)	14
4.244	(*)		Pitch point 0.0854 (0.2169)	16	(*)		Pitch point 0.0854 (0.2169)	16
4.39	(*)		0.0879 (0.2233)	18	(*)		0.0853 (0.2167)	18
6.90	0.0802 (0.2037)	22	0.0861 (0.2187)	18	0.0634 (0.1610)	22	0.0712 (0.1808)	18
7.35	0.0809 (0.2055)	22	0.0853 (0.2167)	18	0.0635 (0.1613)	22	0.0687 (0.1745)	18

* = not computed

The angle α for any position of the involute mesh may be obtained from table 3. What is referred to as contact angle in table 7 is obtained from the formulation

$$\text{Contact angle} = \alpha - 16.61^\circ \quad (25)$$

where 16.61° represents the earliest possible contact angle of the involute mesh. The total angle of rotation of the gear for one cycle of contact is obtained from the difference between the initial and final angles, i.e., $23.96^\circ - 16.61^\circ = 7.35^\circ$. By way of the change of sign of the signum parameter, the pitch point contact for this mesh occurs between $\alpha = 20.81^\circ$ and 20.96° (table 3). A more precise computation, according to equation A-216 (ref 1), gives the value of 20.854° for this angle.

The computations for the clock gear mesh are based on equation 20 for the round on round phase of motion and on equation 22 for the round on flat phase. The pitch point computations, i.e., when the contact points are located on the line of centers, make use of equation 23.

Table 4 furnishes the following required parameters:

$$a_p = 0.09083 \text{ in. (0.2307 cm)}$$

$$p_p = 0.01591 \text{ in. (0.0404 cm)}$$

$$\delta_p = 2.524^\circ$$

In addition, table 4 shows that round on round contact starts when $\phi = 176.2813^\circ$ and that contact coincides with the line of centers shortly after $\phi = 178.0813^\circ$. The latter is indicated by the change of sign of the signum parameter s_R . The round on flat phase of the motion begins at $\phi = 179.7313^\circ$ and ends at $\phi = 183.6313^\circ$.

Similar to equation 25, the contact angle for the clock gear mesh is determined by way of

$$\text{Contact angle} = \phi - 176.2813^\circ \quad (26)$$

The total angle of rotation of the gear for one contact cycle is again 7.35° . The values of the variables ψ , s_R and g , which are needed for the various computations, may also be found in table 4. The necessary values of the angle λ are shown in table 8.

Table 8. Angles ψ (PSID) and λ (LAMDAQ) as functions of angle ϕ (PHID) for same clock gear mesh of table 2

ϕ	ψ	λ
PHID = 176.2813	PSID = 3.5016	LAMDAQ = 262.9153
PHID = 176.4313	PSID = 2.5994	LAMDAQ = 263.0789
PHID = 176.5813	PSID = 1.6993	LAMDAQ = 263.2192
PHID = 176.7313	PSID = .8008	LAMDAQ = 263.3363
PHID = 176.8813	PSID = 359.9038	LAMDAQ = 263.4303
PHID = 177.0313	PSID = 359.0078	LAMDAQ = 263.5013
PHID = 177.1813	PSID = 358.1125	LAMDAQ = 263.5493
PHID = 177.3313	PSID = 357.2178	LAMDAQ = 263.5744
PHID = 177.4813	PSID = 356.3235	LAMDAQ = 263.5767
PHID = 177.6313	PSID = 355.4291	LAMDAQ = 263.5561
PHID = 177.7813	PSID = 354.5347	LAMDAQ = 263.5126
PHID = 177.9313	PSID = 353.6400	LAMDAQ = 263.4462
PHID = 178.0813	PSID = 352.7449	LAMDAQ = 263.3570
PHID = 178.2313	PSID = 351.8491	LAMDAQ = 263.2448
PHID = 178.3813	PSID = 350.9527	LAMDAQ = 263.1097
PHID = 178.5313	PSID = 350.0555	LAMDAQ = 262.9516
PHID = 178.6813	PSID = 349.1574	LAMDAQ = 262.7705
PHID = 178.8313	PSID = 348.2583	LAMDAQ = 262.5662
PHID = 178.9813	PSID = 347.3583	LAMDAQ = 262.3389
PHID = 179.1313	PSID = 346.4573	LAMDAQ = 262.0885
PHID = 179.2813	PSID = 345.5552	LAMDAQ = 261.8148
PHID = 179.4313	PSID = 344.6522	LAMDAQ = 261.5180
PHID = 179.5813	PSID = 343.7482	LAMDAQ = 261.1980

The specific choices of the contact angles in table 7 are based on the various regime changes. Thus,

- C.A. = 0° represents initial contact
- C.A. = 1.80° represents near pitch point contact for the clock gear mesh. (Both equations 20 and 23 are evaluated with the associated data.)
- C.A. = 3.45° represents the beginning of the round on flat phase of the motion of the clock gear mesh.
- C.A. = 4.244° represents pitch point contact for the involute mesh.
- C.A. = 6.90° represents contact at the minimum of the distance g for the clock gear mesh.
- C.A. = 7.35° represents final contact for both meshes.

Computations are omitted whenever no significant changes occur.

Conclusions of Comparison of Distances r_M

The results of table 7 were used to show that the differences in point efficiencies between clock gear and involute meshes, for a given coefficient of friction, are reflections of the associated differences in the magnitudes of the distances r_M .

1. Just as the point efficiency at initial contact is higher for the clock gear mesh than for the involute, regardless of coefficient of friction, the distance r_M is also always larger for the clock mesh at that instant. This difference in magnitude becomes more pronounced as the coefficient of friction is increased.

2. The magnitude of r_M increases after the initial contact in both types of meshes until the pitch point is reached, or until shortly after the pitch point is passed. Parallel increases of point efficiencies, with maxima at or soon after the pitch point may be found in tables 3 and 4.

3. At the pitch point, r_M is independent of the coefficient of friction. The associated value of r_M is somewhat larger for the clock gear mesh. The pitch point is reached after 1.80° of gear rotation, after initial contact, in the clock gear mesh of table 7, while 4.24° of gear rotation for the involute mesh is required. Thus, the angle of approach of the clock mesh is considerably smaller.

4. Just as the point efficiencies of both meshes decrease steadily after the maxima have been reached, there is a continuous decrease in the magnitudes of the associated r_M . For a given coefficient of friction, this decrease is smaller for the involute mesh.

Since, according to equation 22, r_M is proportional to the round on flat phase distance g near the end of contact, the above efficiency decrease may possibly be controlled by increasing the minimum value of g by an appropriate redesign of the tooth.

Any change in geometry which increases the magnitude of the distance r_M will also increase the point efficiency of the mesh.

EFFICIENCY COMPARISONS BETWEEN INVOLUTE AND CLOCK GEAR TYPE TWO AND THREE PASS STEP-UP TRAINS WITH AND WITHOUT SPIN

The physical configurations and the associated analyses are those of the FGTA (ref 1). The two pass and three pass configurations are shown in figures 5 and 6, respectively.

The point efficiency computations for the involute tooth type trains were obtained with the help of programs INVOL3 and INVOL4. The programs CLOCK3 and CLOCK4 supplied the point efficiencies of the clock tooth type trains.

As discussed earlier, the above programs were modified by the introduction of the initialization parameters J_1 . These parameters make it possible to vary the initial points of contact of the individual meshes, and with that allow the determination of that starting configuration of a given train which results in the lowest point efficiency. Investigation showed that the worst starting condition for an involute tooth type train occurs when all meshes make their initial contact at the earliest possible point during approach motion. For clock tooth type trains the worst starting condition is associated with a configuration where all meshes have their motion initiated as late as possible during recess motion. (This has been shown to be true for single pass meshes in the section entitled Efficiency Comparisons between Involute and Clock Gear Type Single Pass Step-up Gear Trains.)

The involute as well as the clock tooth type two pass step-up gear trains were designed with a step-up ratio of 47.265 in order to be comparable to the three pass trains which have a step-up ratio of 47.25 and whose configurations are identical with that of the M125A1 (brass) safing and arming mechanism.

The essential parameters of all fuze gear trains and the specific conditions of the associated computer programs follow. Subsequently, the results of the efficiency comparisons are shown in table 9 and figure 7.

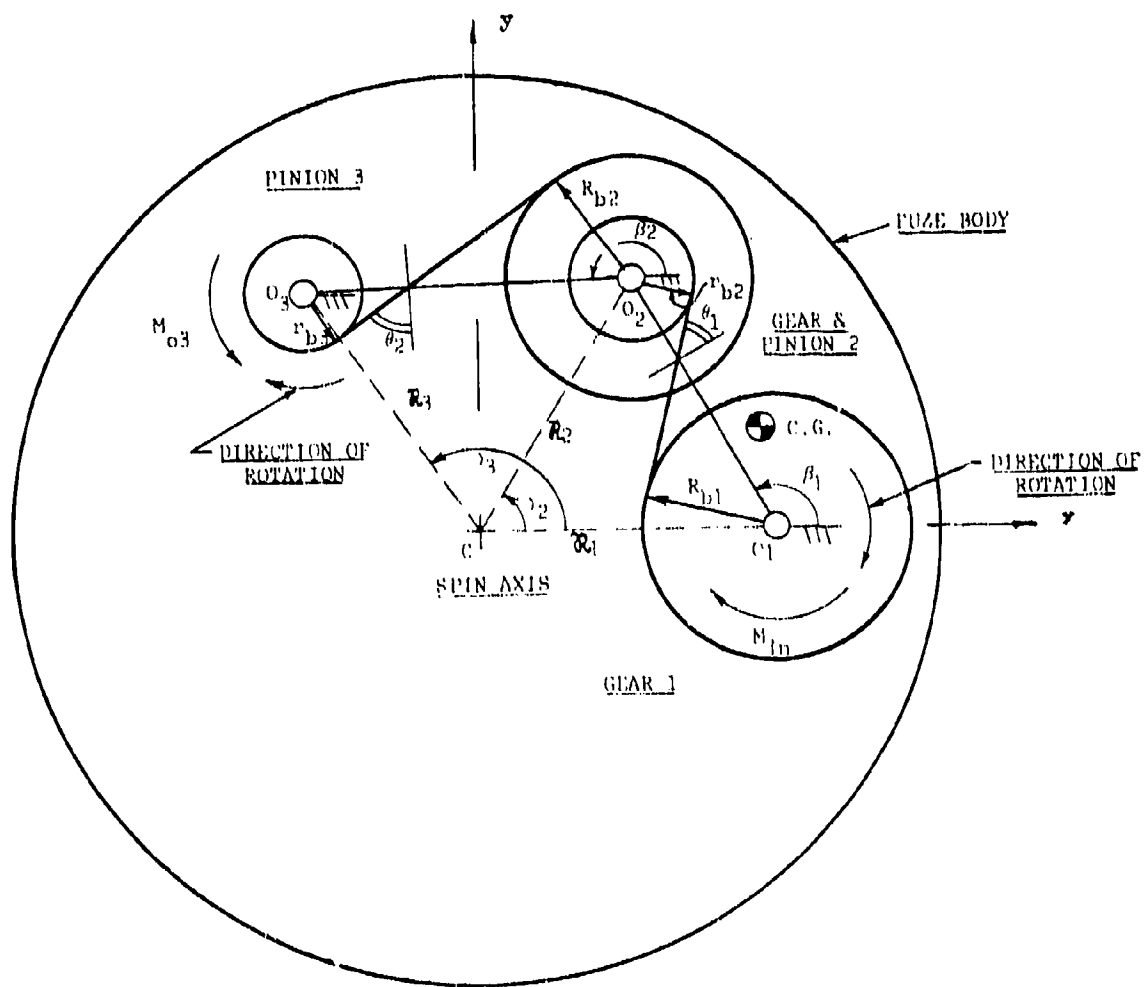


Figure 5. Basic configuration of two pass step-up gear train (shown with involute tooth nomenclature)

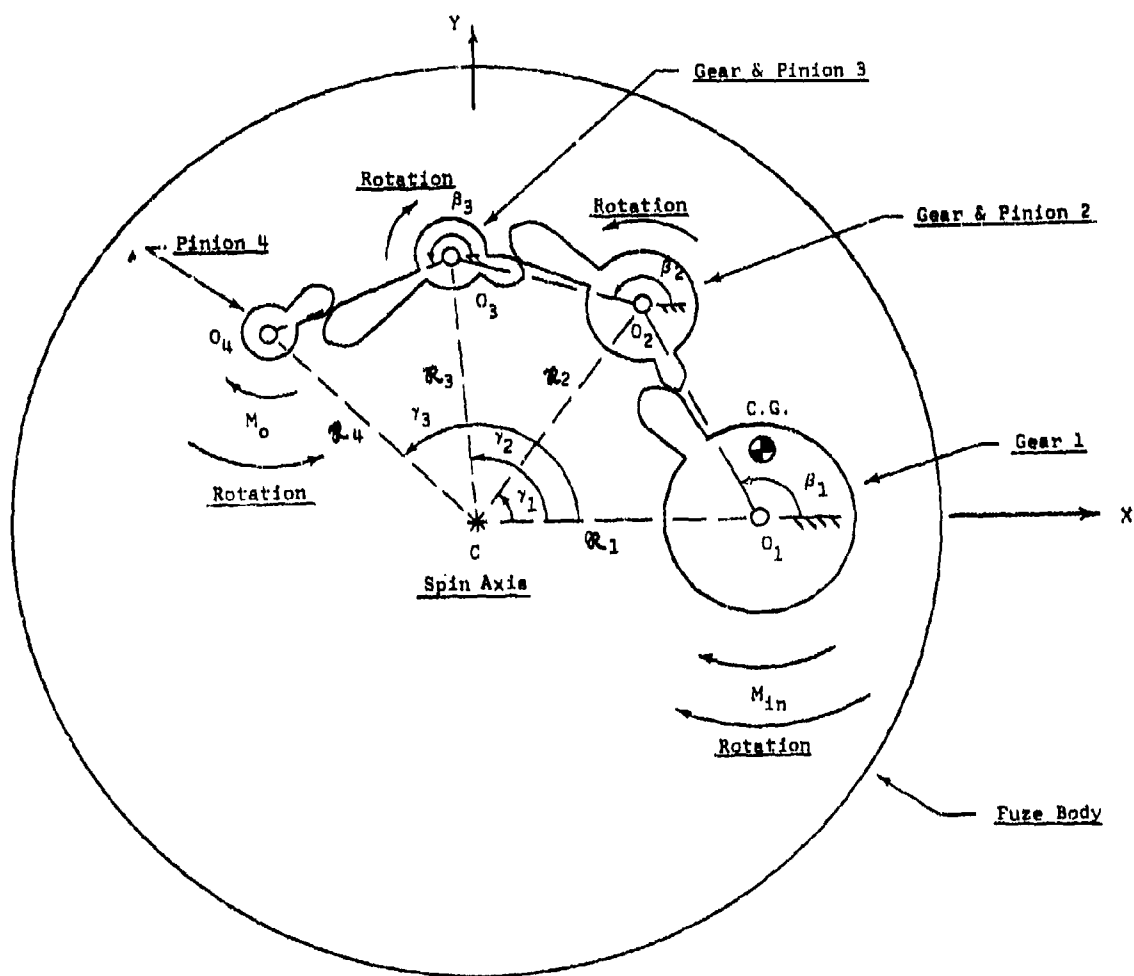


Figure 6. Basic configuration of three pass step-up gear train (shown with clock gear teeth)

Table 9. Step-up gear train comparisons with and without spin*

Number and type	Two step-up mesh efficiency			Three step-up mesh efficiency		
	Initial contact point (ϵ_p)	Maximum point (ϵ_p)	Minimum point (ϵ_p)	Initial contact point (ϵ_p)	Maximum point (ϵ_p)	Minimum point (ϵ_p)
1. Involute, no spin	0.618	0.787	0.618	0.507	0.708	0.507
2. Involute with spin	0.314	0.440	0.314	0.320	0.481	0.320
3. Clock, no spin	0.611	0.794	0.600	0.499	0.699	0.489
4. Clock with spin	0.319	0.448	0.316	0.320	0.476	0.315

* All have worst possible starting condition.

1. Two Pass Step-up Gear Trains (Fig. 5)

The common parameters of both the involute and the clock type two pass gear trains are listed below. Those parameters and program details which are specific to either one of the trains are discussed separately.

Mesh No. 1 (gear 1 and pinion 2)

$P_{d1} = 50$, diametral pitch

$N_{G1} = 55$, number of teeth of gear 1

$N_{P2} = 8$, number of teeth of pinion 2

$R_{p1} = 0.550$ in. (1.397 cm), pitch radius of gear 1

$r_{p2} = 0.080$ in. (0.203 cm), pitch radius of pinion 2

Mesh No. 2 (gear 2 and pinion 3)

$P_{d2} = 70$, diametral pitch

$N_{G2} = 55$, number of teeth of gear 2

$N_{P3} = 8$, number of teeth of pinion 3

$R_{p2} = 0.39286$ in. (0.9979 cm), pitch radius of gear 2

$r_{p3} = 0.05714$ in. (0.1451 cm), pitch radius of pinion 3

Further Common Parameters

$m_1 = 0.12 \times 10^{-3}$ lb-sec²/in. (2.101×10^{-2} kg), mass of gear 1

$m_2 = 0.253 \times 10^{-4}$ lb-sec²/in. (4.430×10^{-3} kg), mass of gear and pinion 2

$m_3 = 0.153 \times 10^{-5}$ lb-sec²/in. (2.679×10^{-4} kg), mass of pinion 3

$\rho_1 = 0.062$ in. (0.157 cm), pivot radius of gear 1

$\rho_2 = 0.025$ in. (0.064 cm), pivot radius of gear and pinion 2

$\rho_3 = 0.018$ in. (0.046 cm), pivot radius of pinion 3

$R_1 = 0.225$ in. (0.572 cm), location of gear 1 from fuze body center

$R_2 = 0.497$ in. (1.262 cm), location of gear and pinion 2 from fuze body center

$R_3 = 0.640$ in. (1.626 cm), location of pinion 3 from fuze body center

$md^2 = 0.275 \times 10^{-5}$ lb-sec²-in. (3.105×10^{-7} kg-m²), the rotor parameter product of gear 1, responsible for input moment M_{in} in inch pounds when the quantity is multiplied by the square of the spin angular velocity.

Parameters and Computational Details Specific to the Involute Tooth Type Two Pass Step-up Gear Train

The gear and pinion parameters which are specific to the two meshes of the involute two pass gear train are listed in appendix B. They are also shown in appendix B as the output listings of program INVOL1, which computes the dimensions of involute meshes with unequal addenda and unity contact ratio. (See reference 1 for program listing and discussion.)

Point efficiency results of two computer runs for two pass involute trains are shown in table 9. Both runs were made with program INVOL4. Run A-1 simulates zero spin velocity, while run A-2 was made for 1000 rpm. An overall coefficient of friction of $\mu = 0.2$ and a range divisor $K = 25$ were used for both runs. (See appendix B for an explanation concerning the range divisor.) To get the lowest possible starting point efficiency, the initialization parameters J_1 and J_2 were set equal to zero. For these conditions both meshes make initial contact at the beginning of their approach motion. To obtain run A-1, which simulates zero spin and with that the absence of any centrifugal forces on the train components, program INVOL4 was modified by introducing the input moment M_{in} , equal in magnitude to one corresponding to a spin of 1000 rpm.³ The output of run A-2 is reproduced in appendix B. The output of run A-1 is not given.

Parameters and Computational Details Specific to the Clock Tooth Type Two Pass Step-up Gear Train

The gear and pinion parameters which are specific to the two meshes of the clock tooth type gear train are listed in appendix E. These parameters were obtained with the help of the computer program BRITSTD, which is shown and discussed in appendix C.

³This moment is given by

$$\begin{aligned} M_{in} = md^2 \omega^2 &= 0.275 \times 10^{-5} \left(\frac{1000 \times 2\pi}{60} \right)^2 \\ &= 0.30157 \times 10^{-1} \text{ in.-lb } (0.34073 \times 10^{-2} \text{ N.m}) \end{aligned}$$

Point efficiency results of two computer runs for two pass clock trains are given in table 9. Results for both runs were obtained with the help of the computer program CLOCK4. Run A-3 was made for zero spin, while run A-4 simulates a spin of 1000 rpm. Again, an overall coefficient of friction $\mu = 0.2$ and a range divisor $K = 25$ were used. Since the lowest starting efficiency for this type of gear train is obtained when both meshes make initial contact at the end of recess motion, the initialization parameters J_1 and J_2 were both set equal to 0.9 for these runs. While run A-3 is not shown in this report, the complete output listing of run A-4 is reproduced in appendix E. To obtain run A-3, which simulates zero spin, the input moment was again directly introduced into program CLOCK4 in the manner discussed earlier in connection with the two pass involute train.

2. Three Pass Step-up Gear Trains

As stated before, the basic configuration of both types of three pass step-up gear trains was taken from that of the M125A1 (brass) safing and arming mechanism. The following first enumerates all parameters which are common to both the involute and the clock tooth type gear trains. Subsequently, those parameters and computational details which are specific to either of the two are discussed separately.

Mesh No. 1 (gear 1 and pinion 2)

$P_{d1} = 44$, diametral pitch

$N_{G1} = 42$, number of teeth of gear 1

$N_{P2} = 8$, number of teeth of pinion 2

$R_{p1} = 0.47727$ in. (1.2123 cm), pitch radius of gear 1

$r_{p2} = 0.09091$ in (0.2309 cm), pitch radius of pinion 2

Mesh No. 2 (gear 2 and pinion 3)

$P_{d2} = 65$, diametral pitch

$N_{G2} = 27$, number of teeth of gear 2

$N_{P3} = 9$, number of teeth of pinion 3

$R_{p2} = 0.20769$ in. (0.5275 cm), pitch radius of gear 2

$r_{p3} = 0.06923$ in. (0.1758 cm), pitch radius of pinion 3

Mesh No. 3 (gear 3 and pinion 4)

P_{d3} = 77, diametral pitch

N_{G3} = 27, number of teeth of gear 3

N_{p4} = 9, number of teeth of pinion 4

R_{p3} = 0.17532 in. (0.4453 cm), pitch radius of gear 3

r_{p4} = 0.05844 in. (0.1484 cm), pitch radius of pinion 4

Further Common Parameters

m_1 = 0.12×10^{-3} lb-sec²/in. (2.101×10^{-2} kg), mass of gear 1

m_2 = 0.85×10^{-5} lb-sec²/in. (1.488×10^{-3} kg), mass of gear and pinion 2

m_3 = 0.34×10^{-5} lb-sec²/in. (5.953×10^{-4} kg), mass of gear and pinion 3

m_4 = 0.15×10^{-5} lb-sec²/in. (2.626×10^{-4} kg), mass of pinion 4

ρ_1 = 0.062 in. (0.157 cm), pivot radius of gear 1

ρ_2 = 0.025 in. (0.064 cm), pivot radius of gear and pinion 2

ρ_3 = 0.018 in. (0.046 cm), pivot radius of gear and pinion 3

ρ_4 = 0.016 in. (0.041 cm), pivot radius of pinion 4

R_1 = 0.225 in. (0.572 cm), location radius of gear 1 from fuze body center

R_2 = 0.436 in. (1.107 cm), location radius of gear and pinion 2 from fuze body center

R_3 = 0.504 in. (1.280 cm), location radius of gear and pinion 3 from fuze body center

R_4 = 0.520 in. (1.321 cm), location radius of pinion 4 from fuze body center

md^2 = 0.275×10^{-5} lb-sec²-in. (3.105×10^{-7} kg-m²), rotor parameter of gear 1, responsible for input moment M_{in} . This quantity becomes in.-lb when multiplied by the square of the spin angular velocity.

Parameters and Computational Details Specific to the Involute Tooth Type Three Pass Step-up Gear Train

The gear and pinion parameters specific to the three pass involute step-up gear train are listed in appendix A. They were originally computed with program INVOL1 (appendix C of ref 1).

Point efficiency results of two computer runs for three pass involute trains are shown in table 9. Results for both runs were obtained with the help of the computer program INVOL3. Run B-1 simulates zero spin velocity, while run B-2 was made for a spin velocity of 1000 rpm. An overall coefficient of friction $\mu = 0.2$ and a range divisor $K = 25$ were used for both runs. Since the lowest starting efficiency for this type of gear train occurs when all three meshes make initial contact as early as possible during their approach motion, the initialization parameters J_1 , J_2 and J_3 were set equal to zero. To obtain run B-1, which simulates zero spin and with that the absence of centrifugal forces on the gear train components, the computer program INVOL3 was also modified by introducing an input moment M_{in} equal in magnitude to a moment which corresponds to a spin of 1000 rpm.

The output listing of run B-2 is reproduced in appendix A. The output listing of run B-1 is not given.

Parameters and Computational Details Specific to the Clock Tooth Type Three Pass Step-up Gear Train

The gear and pinion parameters of the three meshes of the three pass clock step-up gear train are listed in appendix D. These parameters were computed with the help of computer program BRITSTD (appendix C).

Point efficiency results of two computer runs for three pass clock trains are shown in table 9. Results for both runs were obtained by way of the computer program CLOCK3. Run B-3 was made for zero spin, while run B-4 simulates a spin of 1000 rpm. Again, an overall coefficient of friction $\mu = 0.2$ and a range divisor $K = 25$ are used. Since clock type three pass step-up trains experience the lowest point efficiency at starting when all three meshes make initial contact at the end of their recess motion, the initialization parameters J_1 , J_2 and J_3 were set equal to 0.9 for both runs. To obtain run B-3, which simulates zero spin, the input moment M_{in} was again modified in the manner described above for the three pass involute train. The computer output listing of run B-4 is reproduced in appendix D. The output of run B-3 is not given.

3. Conclusions of Efficiency Comparisons and Discussion

Initial contact, maximum and minimum point efficiencies during one tooth cycle of the input gear for two and three pass step-up meshes, with involute and clock type teeth, which operate with or without the presence of spin, are shown in table 9. Graphs of point efficiency versus input gear rotation in a spin environment for the four types of gear trains are shown in figure 7. In each case one tooth cycle of the input gear is shown, using the data in appendixes A, B, D and E (i.e., from computer programs INVOL3, INVOL4, CLOCK3, and

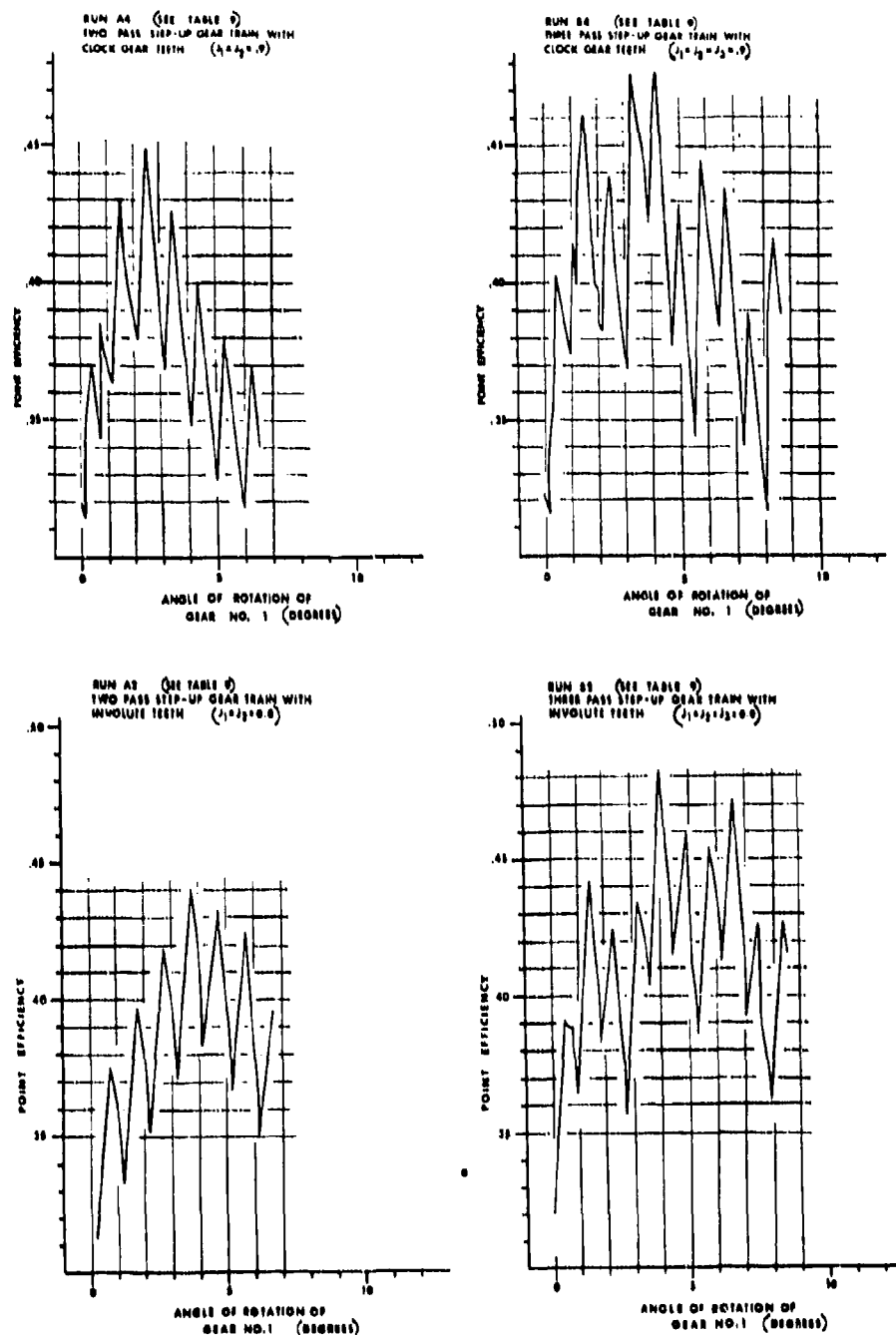


Figure 7. Point efficiencies of two and three pass step-up gear trains in a spin environment for one tooth cycle of the input gear

CLOCK4). All input gear rotation data are adjusted to a zero degree start by subtracting the initial angle in each case.

Subsequently, general factors which influence the point efficiency in multipass step-up gearing are discussed. In addition, an explanation is given for the fact that the mid-cycle efficiencies of the three pass meshes are somewhat higher than those of the two pass meshes when both operate in a spin environment.

The point efficiency comparisons were obtained with the following conditions common to all over-all and component meshes:

a. The worst possible starting conditions were used for all component meshes ($J_1 = 0$, for the involute meshes, and $J_1 = 0.9$, for the clock gear meshes).

b. All meshes have essentially the same step-up ratio (47.265 for the two pass trains and 47.25 for the three pass trains).

c. When spin was simulated, the constant input moment used approximated the one produced by an appropriately sized rotor at a spin rate of 1000 rpm. For the no-spin runs, the identical constant input moment was used.

d. The same coefficient of friction, i.e., $\mu = 0.2$, was used for all meshes and conditions. It applies to pivot as well as to tooth contact friction.

e. All involute meshes have unity contact ratio. This also applies to clock type meshes since in this type of gearing there can never be more than one set of teeth in contact.

Overall Conclusions

The following conclusions were drawn from table 9 and figure 7:

1. For a given mesh and spin condition there is no significant difference in maximum and minimum point efficiencies for the types of involute and clock gearing used. (Compare runs A1 to A3, B1 to B3, A2 to A4, and B2 to B4.)

2. In the absence of spin the two pass step-up meshes show higher maximum and minimum point efficiencies than the three pass meshes. (Compare runs A1 and B1 as well as runs A3 and B3.)

3. While it is somewhat surprising that there is no difference between the initial contact, i.e., minimum, point efficiencies of two and three pass gear trains operating in a spin environment, it is even more surprising that the maximum efficiencies of the three pass trains are somewhat higher than those of the two pass trains. (Compare runs A2 and B2 as well as runs A4 and B4 in table 9.)

The average point efficiency of the three pass gear trains is higher (fig. 7). This fact is reflected by the somewhat higher cycle efficiencies of the three pass trains. (For a definition of the cycle efficiency ϵ_C see equation 4, [ref 1.]) The following values for the various cycle efficiencies are listed at the end of the computer outputs in the previously mentioned appendixes:

two pass involute: $\epsilon_C = 0.385$, three pass involute: $\epsilon_C = 0.414$

two pass clock: $\epsilon_C = 0.379$, three pass clock: $\epsilon_C = 0.404$

These lower efficiencies of the two pass trains have their cause in the need for a heavier gear in the second mesh of these trains. This causes a larger centrifugal force and with that a larger referred pinion friction moment than is the case for the three pass trains. (For detail see the discussion in the section entitled Explanation of Higher Efficiencies of Three-Pass Trains.)

The graphs of the two pass trains show the multiple cyclic variations in point efficiency of the second mesh superposed on the single cycle of point efficiency of the first mesh. Similar superpositions of mesh point efficiencies may be observed in the graphs of the three pass trains.

A decrease in the amplitudes of all cyclic variations, based on geometrical rather than frictional modifications, represents a meaningful optimization goal for this type of gear train (fig. 7). This might be facilitated by decreasing the approach action of all involute meshes as much as possible, while maintaining at least a unity contact ratio.

General Factors which Influence the Point Efficiencies of Multipass Step-up Gear Meshes

To understand the factors which determine the point efficiencies of multipass step-up trains, one must consider the general form which the associated expression takes with or without the presence of spin.

Equation 3 of reference 1 defines point efficiency as

$$\epsilon_p = K_{\text{RATIO}} \frac{M_o}{M_{in}} \quad (27)$$

where

K_{RATIO} = instantaneous angular velocity ratio of the output pinion to the input gear

M_o = the instantaneous output equilibrant moment

M_{in} = the instantaneous input moment

The output moment expression for the various meshes and contact conditions was shown in reference 1 to be of the form⁴

$$M_o = K_{in} M_{in} - \sum K_i \omega^2 \quad (28)$$

where

K_{in} = a constant for a given train configuration which depends on various geometric parameters associated with the gears and pinions of the train. In addition it is a function of the tooth geometry, the pivot locations, the pivot radii, and the overall coefficient of the friction.

K_i = constants which are dependent on the same parameters as K_{in} . In addition they are functions of the individual gear or gear and pinion masses m_i . ($i = 1, 2, 3$ for two pass meshes, while for three pass meshes $i = 1, 2, 3, 4$.)

ω = the constant angular velocity of the fuze body.

For a rotor driven mechanism, with constant spin velocity, the input moment M_{in} has the form

$$M_{in} = m_1 \ell_1 r_c \omega^2 \sin \alpha \quad (29)$$

where

m_1 = mass of the rotor, i.e., of gear 1

ℓ_1 = distance from spin axis to rotor pivot axis

r_c = distance of rotor center of mass from rotor pivot axis

α = rotor angle with respect to fuze body

Substitution of equations 28 and 29 into equation 27, followed by some rearrangement of terms, gives the following expression for the point efficiency of spin rotor driven gear meshes:

$$\epsilon_p = K_{RATIO} \left(K_{in} - \frac{\sum K_i}{K_{in} m_1 \ell_1 r_c \sin \alpha} \right) \quad (30)$$

⁴See the following expressions in reference 1: A-125, A-193, H-81, H-118, H-158, H-180, H-216, H-218, H-239, H-241, H-260, H-261, H-277, and H-278.

Equation 30 shows that the point efficiency is independent of spin velocity. It may be maximized for a given configuration by making the constant K_{in} together with the denominator of the second term inside the parenthesis as large as possible, while keeping the summation term as small as possible.

No conclusions concerning the influence of the angular velocity ratio K_{RATIO} on the point efficiency may be drawn since the terms inside the parenthesis are also related to various gear ratios.

In case these types of gear trains operate without spin and the input moment is supplied by a spring, equation 28 becomes

$$M_o = K_{in} M_{in} , \quad (31)$$

and the point efficiency expression (equation 27) reduces to

$$\epsilon_p = K_{RATIO} K_{in} \quad (32)$$

For a given velocity ratio of the train, the point efficiency can again be maximized by maximizing the constant K_{in} . This value is larger for a two pass configuration than for a three pass. (Refer to cases 1 and 3 of table 9.)

Explanation of Higher Efficiencies of Three-Pass Trains

The unexpectedly equal or higher point efficiencies of the three pass meshes, when compared with those of the two pass meshes, may be principally explained by the need for a larger pitch radius, and with that of a larger mass, for gear no. 2.⁵ This larger mass, and the associated larger spin axis to pivot axis distance, causes a larger centrifugal force and with that a larger pivot friction moment than is the case for the comparable mesh of the three pass train with its lower step-up ratio. In addition, the increased step-up ratio contributes to the decrease in the available input moment. (See discussion concerning referred friction moments below.)

The above is best illustrated by comparing the sums of the individual pivot friction moments due to centrifugal forces only, as referred to the input gear, for both types of gear trains.

⁵Every effort was made during the design of the two pass train to keep the gear and pinion masses, together with the spin axis to pinion axis distance, as small as possible (table 10).

If the friction moment on an individual gear and, or, pinion is given by M_{fi} , the referred friction moment M_{f1i} , acting on the input gear, may be found by way of the principle of virtual work from

$$M_{f1i} = M_{fi} \dot{\phi}_i / \dot{\phi}_1 \quad (33)$$

where

$\dot{\phi}_i / \dot{\phi}_1$ = angular velocity ratio between the i th gear and, or, pinion and gear no. 1 (Average values must be used for clock type gears.)

i = the gear or pinion number. For the two pass train $i = 1, 2, 3$ and for the three pass train $i = 1, 2, 3, 4$.

The friction moment due to the centrifugal force only on any individual component is given by

$$M_{fi} = m_i \delta r_i \rho_i \omega^2 \quad (34)$$

where

m_i = mass of individual component

δr_i = distance from spin axis to individual pivot axis

ρ_i = individual pivot radius

μ = coefficient of friction

The parameters of equations 33 and 34 together with the referred moments M_{f1i} for both types of gear trains are listed in table 10. The sum of the referred friction moments is higher for the two pass meshes than for the three pass meshes, and thus represents a greater reduction of the identical input moment. For a spin rate of 1000 rpm and a coefficient of friction of $\mu = 0.2$, these friction moments become 1.02×10^{-2} and 0.71×10^{-2} in.-lb, respectively. This shows a considerable increase of friction for the two pass train if one considers that the input moment M_{in} has a magnitude of 3.01×10^{-2} in.-lb. (See data printouts in the various computer programs in the appendixes.)

Table 10. Comparison of referred friction moments

Parameter	Two pass train	Three pass train
R_1	0.225 in. (0.572 cm)	0.225 in. (0.572 cm)
R_2	0.497 (1.262)	0.436 (1.107)
R_3	0.640 (1.626)	0.504 (1.280)
R_4	-	0.520 (1.321)
m_1	0.120×10^{-3} lb-in. ² /in. (2.101×10^{-2} kg)	0.120×10^{-3} lb-in. ² /in. (2.101×10^{-2} kg)
m_2	0.253×10^{-4} (4.430×10^{-3})	0.850×10^{-5} (1.488×10^{-3})
m_3	0.153×10^{-5} (2.679×10^{-4})	0.340×10^{-5} (5.953×10^{-4})
m_4	-	0.150×10^{-5} (2.62×10^{-4})
p_1	0.062 in. (0.157 cm)	0.062 in. (0.157 cm)
p_2	0.025 (0.064)	0.025 (0.064)
p_3	0.018 (0.046)	0.018 (0.046)
p_4	-	0.016 (0.041)
ϕ_2/ϕ_1	6.875	5.25
ϕ_3/ϕ_1	47.265	15.75
ϕ_4/ϕ_1	-	47.25
M_{f11}	1.674×10^{-6} $\mu\omega^2$ in.-lb (0.189×10^{-6} $\mu\omega^2$ (N.m))	1.674×10^{-6} $\mu\omega^2$ in.-lb (0.189×10^{-6} $\mu\omega^2$ (N.m))
M_{f12}	21.61×10^{-7} $\mu\omega^2$ (0.244×10^{-6} $\mu\omega^2$)	4.864×10^{-7} $\mu\omega^2$ (0.550×10^{-7} $\mu\omega^2$)
M_{f13}	8.331×10^{-7} $\mu\omega^2$ (0.941×10^{-7} $\mu\omega^2$)	4.858×10^{-7} $\mu\omega^2$ (0.549×10^{-7} $\mu\omega^2$)
M_{f14}	-	5.897×10^{-7} $\mu\omega^2$ (0.666×10^{-7} $\mu\omega^2$)
Sum of referred Friction moments	46.681×10^{-7} $\mu\omega^2$ (5.275×10^{-7} $\mu\omega^2$)	32.359×10^{-7} $\mu\omega^2$ (3.657×10^{-7} $\mu\omega^2$)

REFERENCES

1. G.G. Lowen, City College of N.Y., and F.R. Tepper, ARRADCOM, "Fuze Gear Train Analysis," Technical Report ARLCD-TR-79030, ARRADCOM, Dover, NJ, December 1979.
2. British Standard No. 978 for Gears for Instruments and Clockwork Mechanisms, Part 2, Cycloidal Type Gears (1952).

APPENDIX A
COMPUTER PROGRAM INVOL3 (REVISED)

The original program descriptions were given in appendix C of Fuze Gear Train Analysis (ref A-1). The present appendix contains revised descriptions, listings and sample outputs of computer program INVOL3, which computes point and cycle efficiencies for three pass involute gear trains in a spin environment. All meshes have unity contact ratio.

The following changes were made:

1. The diametral pitches of all three meshes are given as data and are printed in the output.
2. The numbers of teeth of all three meshes are given as data and are printed in the output.
3. The initialization parameters J (one for each mesh) are introduced. They are given as part of the data and are printed in the output. This parameter allows the initial point of contact of a given mesh to be chosen at an arbitrary point within the range of possible contact points.
4. The angles β (equations A-200 and A-202, ref A-1) are now printed out by the program in order to be able to judge the effects of various changes in the configuration of the gear train.

The computer program INVOL3 is based on the moment input-output relationship for a three pass step-up gear train operating in a spin environment. All meshes have unity contact ratio. The nomenclature of the program is chosen to coincide as closely as possible with that of the original derivations. The expressions for the contact geometry and other auxiliary geometric terms may be found in appendix A (ref A-1).

Input Parameters

The following parameters represent the input data for the program. Those which involve gear dimensions only must be obtained from the results of INVOL1 (ref A-1) since the moment expressions are derived for unity contact ratio only:

$$PSUBD1 = r_{d1}$$

$$PSUBD2 = r_{d2}$$

$$PSUBD3 = r_{d3}$$

$$NG1 = N_{G1}$$

$$NP2 = N_{P2}$$

$$NG2 = N_{G2}$$

NP3 = N_{p3}

NG3 = N_{G3}

NP4 = N_{p4}

MU = μ , coefficient of friction at all pivots and at all tooth contact points

RPM, revolutions per minute of the fuze body

CAPRP1 = R_{p1}

CAPRP2 = R_{p2}

CAPRP3 = R_{p3}

RP2 = r_{p2}

RP3 = r_{p3}

RP4 = r_{p4}

THETA1 = θ_1

THETA2 = θ_2

THETA3 = θ_3

ISTOP, arbitrary single digit integer for multiple data sets. It must be zero for last set of data.

R1 = R_1

R2 = R_2

R3 = R_3

R4 = R_4

RHO1 = ρ_1

RHO2 = ρ_2

RHO3 = ρ_3

RHO4 = ρ_4

CAPRB1 = R_{b1}

CAPRB2 = R_{b2}

CAPRB3 = R_{b3}
 RB2 = r_{b2}
 RB3 = r_{b3}
 RB4 = r_{b4}
 CAPR01 = R_{o1}
 CAPR02 = R_{o2}
 CAPR03 = R_{o3}
 R02 = r_{o2}
 R03 = r_{o3}
 R04 = r_{o4}
 M1 = m_1 , mass of input gear 1
 M2 = m_2 , mass of gear and pinion 2
 M3 = m_3 , mass of gear and pinion 3
 M4 = M_4 , mass of pinion 4
 MD = md^2 , mass-distance product contained in the
 expression for the input moment M_{in}
 K = K_3 , the range divisor which is associated with
 gear 3, the driving gear of the last mesh (eq. A-211,
 ref A-1)

J1, J2, J3, initialization parameters

Computations

Computation of MIN, GAMMAS and BETAS

To start with, the program computes the input moment

$$MIN = M_{in} = md^2 \omega^2 \quad (A-1)$$

Subsequently, the angles $\gamma_2, \gamma_3, \gamma_4$ and $\beta_1, \beta_2, \beta_3$ are established according to the expressions given in appendix A (ref A-1).

Determination of the Gear Train Constants

The determination of the gear train constants consists of the following:

RATIO = KRATIO (eq 2, ref A-1). Since the angular velocity is constant, this parameter may be expressed in terms of the applicable base radii, i.e.,

$$\frac{R_{b1} \times R_{b2} \times R_{b3}}{r_{b2} \times r_{b3} \times r_{b4}}$$

TEST1, TEST2, and TEST3 represent the tangent functions of the mesh pressure angles, which are used in conjunction with the values of the signum functions s.

D1, D2, and D3 are given by equations A-204, A-217, and A-223, reference 1, respectively, and represent the distances between the points of tangency to the base circles along the lines of action of the three meshes.

MTOT = 0 represents the initialization of the sum of the output moments. This is used for the determination of the cycle efficiency.

Determination of Earliest and Latest Possible Values of ALPHAS, Initialization of ALPHAS. Centrifugal Forces

The determination of the earliest and latest possible angles of rotation is accomplished with the help of subroutine ALPHA, at the end of the program, which makes use of equations A-205, A-206, A-218, A-219, A-224, and A-225, reference A-1. The angles of initial contact α_i are determined with the help of the initialization parameters J_i according to:

$$\alpha_i = \alpha_{iIN} + J_i(\alpha_{iFIN} - \alpha_{iIN}) \quad (i=1,2,3) \quad (A-2)$$

The additional parameter J_4 serves to distinguish between the two possible contact conditions of mesh no. 1. $J_4 = 0$ when the first set of teeth is in contact. $J_4 = 1$ when the latest possible value of α_1 has been reached and contact is transferred to the second set of teeth. $J_4 = 0$ at all times when $J_1 = 0$, i.e., contact is made in mesh no. 1 at the earliest possible point, and, therefore, contact need never be transferred to the second set of teeth to obtain a complete cycle (cards no. 116 and 131).

The angular increments of gears 3, 2, and 1, i.e., DELAL3, DELAL2, and DELAL1 are determined with the help of equations A-211 through A-213 (ref A-1), respectively.

The centrifugal forces, which act on the pivots of the various gear and/or pinion assemblies, are obtained by way of equations A-33, A-57, A-84, and A-107 (ref A-1).

Point and Cycle Efficiencies

Both point and cycle efficiencies are based on equations A-125 (ref A-1) for the output moment $M_{O4} = M_{O4}$.

The point efficiency is computed directly in the manner of equation 3, (ref A-1) i.e.,

$$\epsilon_p = K_{RATIO} \frac{M_{O4}}{M_{IN}} = \text{POINTEFF} \quad (\text{A-3})$$

The cycle efficiency is treated in the manner of equations C-8, (ref A-1), i.e.,

$$\epsilon_p = \frac{K_{RATIO} \Delta \alpha_1 \Sigma M_{O4}}{M_{IN} (\alpha_{1FIN} - \alpha_{1IN})} = \text{CYCLEFF} \quad (\text{A-4})$$

The program gives the summation as

$$MTOT = \Sigma M_{O4} \quad (\text{A-5})$$

Gear Train Motion Model

The simulation of the gear train motion, which is necessary for the computation of both POINTEFF and CYCLEFF, is found in a loop which starts with statement label no. 14 (card no. 129) and ends with card no. 215. As discussed earlier, the motions of the individual driving gears are initialized with the help of the parameters J_1 , J_2 , and J_3 . The position of each mesh is subsequently incremented by the appropriate DELAL1, DELAL2, or DELAL3. Whenever the J_i 's ($i=1,2,3$) are not equal to zero, and one of the angles α_{iFIN} has been reached, the particular mesh is reset to its respective angle α_{iIN} . Since mesh 2 and 3 go through numerous cycles while mesh 1 goes through one cycle, this type of resetting occurs many times (cards no. 129 and 130). When $J_1 = 0$, i.e., contact in mesh 1 is made at the earliest possible point, CYCLEFF is determined and the computation is ended once the angle $\alpha_{1FIN} - \text{DELAL1}$ is reached. When $J_1 \neq 0$, the above occurs when ALPHA1 reaches the magnitude of its initial angle minus DELAL1. (The nature of the numerical integration requires that only K computations be included.)

The values of the signum functions s_1 , s_2 , and s_3 are determined continuously according to equations A-216, A-222, and A-227 (ref A-1).

The instantaneous distances to the contact points, i.e., $A_1 = a_1$ and $A_2 = a_2$, and $A_3 = a_3$ are determined for each of the meshes by an appropriate adaptations of equation A-203 (ref A-1) (also eqs A-214, A-220, and A-226, ref A-1).

The determination of the instantaneous output moment $M_{O4} = M_{o4}$ requires the continuous computation of the variable quantities A_1 to A_{20} , C_1 to C_6 and D_1 to D_4 , which are given originally in conjunction with the various equilibrium conditions in appendix A (ref A-1). The program uses the following nomenclature for these variables:

AA1 to AA20

CC1 to CC6

DD1 to DD4

Output

Again, the output of the program is best explained by means of the sample computation which is shown at the end of the program. This example uses the gear data of the first three sample computations of program INVOL1. The output lists the following:

Input Parameters

Mesh No. 1

CAPRP1 = R_{p1} = 0.47727 in. (1.2123 cm)	PSUBD1 = P_{d1} = 44
CAPRB1 = R_{b1} = 0.44849 in. (1.13916 cm)	NG1 = N_{G1} = 42
CAPRO1 = R_{o1} = 0.48791 in. (1.2393 cm)	NP2 = N_{P2} = 8
RP2 = r_{p2} = 0.09091 in. (0.2309 cm)	J1 = 0
RB2 = r_{b2} = 0.08543 in. (0.2170 cm)	
RO2 = r_{o2} = 0.11000 in. (0.2794 cm) (This is a ROFIN as given by INVOL1.)	

Also,

THETA1 = θ_1 = 20°

Mesh No. 2

CAPRP2 = R_{p2} = 0.20769 in. (0.5275 cm)	PSUBD2 = P_{d2} = 65
CAPRB2 = R_{b2} = 0.19517 in. (0.4957 cm)	NG2 = N_{G2} = 27

CAPR02 = R_{o2} = 0.21579 in. (0.5481 cm) NP3 = N_{p3} = 9
 RP3 = r_{p3} = 0.06923 in. (0.1758 cm) J2 = 0
 RB3 = r_{b3} = 0.06506 in. (0.1652 cm)
 RO3 = r_{o3} = 0.08089 in. (0.2055 cm)

Also

THETA2 = θ_2 = 20°

Mesh No. 3

CAPRP3 = R_{p3} = 0.17532 in. (0.4453 cm) PSUBD3 = P_{d3} = 77
 CAPRB3 = R_{b3} = 0.16475 in. (0.4183 cm) NG3 = N_{G3} = 27
 CAPRO3 = R_{o3} = 0.18216 in. (0.4627 cm) NP4 = N_{p4} = 9
 RP4 = r_{p4} = 0.05844 in. (0.1484 cm) J3 = 0
 RB4 = r_{b4} = 0.05492 in. (0.1395 cm)
 RO4 = r_{o4} = 0.06828 in. (0.1734 cm)

Also,

THETA3 = θ_3 = 20°

In addition,

MU = μ = 0.2
 RPM = 1000
 M1 = m_1 = 0.12×10^{-3} lb-sec²/in. (2.101×10^{-2} kg)
 M2 = m_2 = 0.85×10^{-5} lb-sec²/in. (1.488×10^{-3} kg)
 M3 = m_3 = 0.34×10^{-5} lb-sec²/in. (5.952×10^{-4} kg)
 M4 = m_4 = 0.15×10^{-5} lb-sec²/in. (2.626×10^{-4} kg)
 R1 = R_1 = 0.225 in. (0.5715 cm)
 R2 = R_2 = 0.436 in. (1.1074 cm)
 R3 = R_3 = 0.504 in. (1.2802 cm)
 R4 = R_4 = 0.520 in. (1.3208 cm)

RHO1 = ρ_1 = 0.062 in. (0.1575 cm)
 RHO2 = ρ_2 = 0.025 in. (0.0635 cm)
 RHO3 = ρ_3 = 0.018 in. (0.0457 cm)
 RHO4 = ρ_4 = 0.016 in. (0.0406 cm)
 MD = md^2 = 0.275×10^{-5} lb-sec²-in. (3.105×10^{-7} kg-m²)
 K = 25

Computed Values

The point efficiency is given as a function of the angle α_1 , together with the signum parameters s_1 , s_2 , and s_3 (given for checking purposes). The cycle efficiency is shown at the end of the output. In addition, the input moment MIN is printed out as well as BETA1D, BETA2D, AND BETA3D.


```

WRITE(6,11)CAPR81,CAPR82,CAPR83,R82,R5,R84
WRITE(6,12)CAPR31,CAPR32,CAPR33,R32,R33,R34
WRITE(6,13)MD,K,JI,J2,J3
WRITE(6,200)BETAID,BETA2,BETA3
200 FORN1(6X,BETAID=,F7.2,3X,BETA2=,F7.2,3X,BETA3=,F7.2//)
8 FORMAT(=,5X,PSUBD1=,F5.0,3X,PSUBD2=,F5.0,3X,PSUBD3=,
1F5.0//6X,NG1=,F4.0,3X,NG2=,F4.0,3X,NG3=,F4.0,3X,NG3=,F4.0//
3 6X,MIN=,E12.5,3X,MP4=,F6.3,3X,MPH=,F6.0//
46X,CAPR1=,F8.5,3X,CAPR2=,F8.5,3X,CAPR3=,F8.5//6X,
5-R2=,F8.5,3X,RP3=,F8.5,3X,RP4=,F8.5//6X,
6-THET1=,F9.5,3X,THET2=,F9.5,3X,THET3=,F9.5//)
9 FORMAT(6X,R1=,F7.5,3X,R2=,F7.5,3X,R3=,F7.5,3X,R4=,F7.5,
1//6X,R1=,F7.5,3X,R2=,F7.5,3X,R3=,F7.5,3X,R4=,F7.5,3X,
2-V4=,E15.5//)
10 FORMAT(6X,RH31=,F7.5,3X,RH32=,F7.5,3X,RH33=,F7.5,3X,
1-RH4=,F7.5//)
11 FORMAT(6X,CAPR1=,F7.5,3X,CAPR2=,F7.5,3X,CAPR3=,F7.5,
13X,R82=,F7.5,3X,R83=,F7.5,3X,R84=,F7.5//)
12 FORMAT(6X,CAPR1=,F7.5,3X,CAPR2=,F7.5,3X,CAPR3=,F7.5,3X,
1,R82=,F7.5,3X,R83=,F7.5,3X,R84=,F7.5//)
13 FORMAT(6X,MD=,E10.3//6X,RANGE DIVISOR=,14//6X,JI=,F4.2,
13X,J2=,F4.2,3X,J3=,F4.2//)
C
C CONVERSION TO RADIAN
C
C Z = PI/180.
C THETA1 = THETA1*Z
C THETA2 = THETA2*Z
C THETA3 = THETA3*Z
C
C DETERMINATION OF GEAR TRAIN CONSTANTS
C
C RATIO = CAPR3*CAPR2*CAPR1/(R82*R83*R84)
C TEST1 = TAN(THETA1)
C TEST2 = TAN(THETA2)
C TEST3 = TAN(THETA3)
C D1 = (CAPR1 + R82)*TAN(THETA1)
C D2 = (CAPR2 + R83)*TAN(THETA2)
C D3 = (CAPR3 + R84)*TAN(THETA3)
C MTD = 0.
C
C DETERMINATION OF EARLIEST AND LATEST POSSIBLE VALUES OF ALPHAS
C
C CALL ALPHA(CAPR81,R82,THETA1,CAPR81,R82,ALFIN,ALFIN)
C CALL ALPHA(CAPR82,R83,THETA2,CAPR82,R83,AL2IN,AL2FIN)
C CALL ALPHA(CAPR83,R84,THETA3,CAPR83,R84,AL3IN,AL3FIN)
C
C DELA13 = (AL3FIN - AL3IN)/K
C DELA12 = DELA13*R83/CAPR82
C DELA11 = DELA12-R82/CAPR81
C
C INITIALIZATION OF ALPHAS
C
C ALPHA1 = AL1IN + (AL1FIN-AL1IN)*J1
C ALPHA2 = AL2IN + (AL2FIN-AL2IN)*J2
C ALPHA3 = AL3IN + (AL3FIN-AL3IN)*J3

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Computer program INVOL3 (cont)

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```

115      ALPHA1 = ALPHA1
      J4 = 0
      C
      C CENTRIFUGAL FORCES
      C
120      T1 = W1*R1*OM2
      T2 = W2*R2*OM2
      T3 = W3*R3*OM2
      T4 = W4*R4*OM2
      C
125      DENOM = 1. + MU*WU
      C
      C UPDATE VALUES OF ALPHAS
      C
130      14 IF(ALPHA2 .GT. AL2FIN)ALPHA2 = AL2IN
      IF(ALPHA3 .GT. AL3FIN)ALPHA3 = AL3IN
      IF(ALPHA1 .GT. AL1FIN)J4=1
      IF(ALPHA1 .GT. AL1FIN)ALPHA1=AL1IN
      C
      C TEST TO DETERMINE IF CONTACT POINT IS IN APPROACH OR RECESS
      C
135      IF APPROACH, S = 1.
      IF RECESS, S = -1.
      AT PITCH POINT, S = G.
      C
140      IF(ALPHA1 .LT. TEST1)S1 = 1.
      IF(ALPHA2 .LT. TEST2)S2 = 1.
      IF(ALPHA3 .LT. TEST3)S3 = 1.
      IF(ALPHA1 .GT. TEST1)S1 = -1.
      IF(ALPHA2 .GT. TEST2)S2 = -1.
      IF(ALPHA3 .GT. TEST3)S3 = -1.
      IF(ALPHA1 .EQ. TEST1)S1 = 0.
      IF(ALPHA2 .EQ. TEST2)S2 = 0.
      IF(ALPHA3 .EQ. TEST3)S3 = 0.
      C
145      C DETERMINATION OF INPUT FOR MOMENT EXPRESSIONS
      C
150      A1 = ALPHA1*CAPR81
      A2 = ALPHA2*CAPR82
      A3 = ALPHA3*CAPR83
      AA1 = ABS((SIN(GAMMA4) - MU*CDG(GAMMA4))/DENOM)
      AA2 = ABS((1.+S3*WU*WU)*COS(BETA3+THETA3) + MU*(1.-S3)
      1*SIN(BETA3+THETA3))/DENOM)
      AA3 = ABS((COS(GAMMA4) + MU*SIN(GAMMA4))/DENOM)
      AA4 = ABS((1.+S3*WU*WU)*SIN(BETA3+THETA3) - MU*(1.-S3)
      1*COS(BETA3+THETA3))/DENOM)
      AA5 = ABS((1.+WU*WU*S2)*COS(BETA2-THETA2) + MU*(S2-1.)
      1*SIN(BETA2-THETA2))/DENOM)
      AA6 = ABS((SIN(GAMMA3) + MU*CDG(GAMMA3))/DENOM)
      AA7 = ABS((1.-WU*WU*S3)*COS(BETA3+THETA3) - MU*(1.+S3)
      1*SIN(BETA3+THETA3))/DENOM)
      AA8 = ABS((1.+WU*WU*S2)*SIN(BETA2-THETA2) + MU*(1.-S2)
      1*COS(BETA2-THETA2))/DENOM)
      AA9 = ABS((MU*SIN(GAMMA3) - COS(GAMMA3))/DENOM)
      AA10 = ABS((1.-WU*WU*S3)*SIN(BETA3+THETA3) + MU*(1.+S3)
      1*COS(BETA3+THETA3))/DENOM)
      AA11 = ABS((WU*(1.-S1)*SIN(BETA1+THETA1) + (1.+S1*WU*WU)
      1*COS(BETA1+THETA1))/DENOM)

```

Computer program INVOL3 (cont)

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175      AA12 = ABS((SIN(GAMMA2) - MU-COS(GAMMA2))/DENOM)
          AA13 = ABS((MU*(1.+S2)*SIN(BETA2-THETA2) + (1.-MU-MU*S2)
          1+COS(BETA2-THETA2))/DENOM)
          AA14 = ABS((MU*(1.-S1)*COS(BETA1+THETA1) - (1.-MU-MU*S1)
          1*SIN(BETA1+THETA1))/DENOM)
          AA15 = ABS((MU-SIN(GAMMA2) + COS(GAMMA2))/DENOM)
          AA16 = ABS(((1.-MU-MU*S2)*SIN(BETA2-THETA2) - MU*(1.+S2)
          1+COS(BETA2-THETA2))/DENOM)
          AA17 = ABS(((1.-MU-MU*S1)*SIN(BETA1+THETA1) + MU*(1.+S1)
          1+COS(BETA1+THETA1))/DENOM)
          AA18 = ABS(1./DENOM)
          AA19 = ABS((MU*(1.+S1)*SIN(BETA1+THETA1) - (1.-MU-MU*S1)
          1+COS(BETA1+THETA1))/DENOM)
          AA20 = ABS(MU/DENOM)
          DD1 = R84 - MU*(S3*(D3-A3) + RHO4*(AA2+AA4))
          DD2 = -MU*(RHO3*(AA5+AA8) + S2*(D2-A2)) + R83
          DD3 = R82 - MU*(S1*(D1-A1) + RHO2*(AA1+AA14))
          DD4 = CAPR81 - MU*(S1*A1 - RHO1*(AA17+AA19))
          CC1 = MU-RHO4*(AA1+AA3)
          CC2 = CAPR83 - MU*(S3*A3 - RHO3*(AA7+AA10))
          CC3 = MU-RHO3*(AA6+AA9)
          CC4 = CAPR82 - MU*(S2*A2 - RHO2*(AA13+AA16))
          CC5 = MU-RHO2*(AA12+AA15)
          CC6 = MU-RHO1*(AA18+AA20)

180      C OUTPUT MOMENT
          C
          C
          ALPHA10 = ALPHA1-180./PI
          MO4 = DD1-DD2-DD3/(CC2-CC4-DD4)*(MIN-T1-CC6) - T2-CC5-DD1-DD2
          1/(CC2-CC4) - T3-CC3-DD1/CC2 - T4-CC1
          POINTEF = RATIO-MO4/MIN
          WRITE(6,15)ALPHID,S1,S2,S3,POINTEF
15      FORMAT(6X,'ALPHA1 =',F6.2,' (DEG),3X,'S1 =',F5.1,3X,'S2 =',F5.1,
          13X,'S3 =',F5.1,3X,'POINT EFFICIENCY =',F7.5)
          MTOT = MTOT + MO4

200      C ADVANCE GEAR TRAIN TO NEXT POSITION
          C
          C
          ALPHA1 = ALPHA1 + DELA11
          IF(IJ4.EQ.1 .AND. ALPHA1.GT.ALPHA1-DELA11) .OR. (J1.EQ.0. .AND.
          1ALPHA1.GT.ALPHA1-DELA11)GO TO 16
          ALPHA2 = ALPHA2 + DELA12
          ALPHA3 = ALPHA3 + DELA13
          GO TO 14

210      16 CYCLEFF = RATIO-DELA1-MTOT/(MIN*(AL1FIM-AL1IM))
          WRITE(6,17)CYCLEFF
          17 FORMAT('0',5X,'CYCLE EFFICIENCY =',F5.3)
          IF(IISTOP .NE. 0)GO TO 100
          STOP
          END
220

```

Computer program INVOL3 (cont)

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SUBROUTINE ALPHA

```

1      SUBROUTINE ALPHA(CAPRB,RB,THETA,CAPRO,RQ,ALIN,ALFIN)
      C
      C      THIS SUBROUTINE COMPUTES THE INITIAL AND FINAL VALUES OF ALPHAS
      C
5      ALIN = ((CAPRB + RB)*TAN(THETA) - SORT(RQ*RQ - RB*RB))/CAPRB
      ALFIN = SORT(CAPRO*CAPRO - CAPRB*CAPRB)/CAPRB
      RETURN
      END

```

Computer program INVOL3 (cont)

PSUBD1 = 44. PSUBD2 = 65. PSUBD3 = 77.
 NG1 = 42. NP2 = 8. NG2 = 27. NP3 = 9. NG3 = 27. NP4 = 9.
 MIN = .30157E-01 MU = .200 RPM = 1000.
 CAPRP1 = .47727 CAPRP2 = .20769 CAPRP3 = .17532
 RP2 = .09091 RP3 = .06923 RP4 = .05844
 THETA1 = 20.00000 THETA2 = 20.00000 THETA3 = 20.00000
 R1 = .22500 R2 = .43600 R3 = .50400 R4 = .52000
 M1 = .12000E-03 M2 = .85000E-05 M3 = .34000E-05 M4 = .15000E-05
 RHO1 = .06200 RHO2 = .02500 RHO3 = .01800 RHO4 = .01600
 CAPRB1 = .44949 CAPRB2 = .19517 CAPRB3 = .16475 RB2 = .08543 RB3 = .06506 RB4 = .05492
 CAPRO1 = .48791 CAPRO2 = .21579 CAPRO3 = .18216 RO2 = .11000 RO3 = .08089 RO4 = .06828
 MD = .275E-05

RANGE DIVISOR = 25

J1 = 0.00 J2 = 0.00 J3 = 0.00

BETA1D = 135.82 BETA2D = 207.77 BETA3D = 247.36

ALPHA1 = 15.97 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .32011
ALPHA1 = 16.01 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .32510
ALPHA1 = 16.04 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .33014
ALPHA1 = 16.08 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .33522
ALPHA1 = 16.11 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .34035
ALPHA1 = 16.14 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .34552
ALPHA1 = 16.18 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .35075
ALPHA1 = 16.21 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .35602
ALPHA1 = 16.24 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .36134
ALPHA1 = 16.28 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .36671
ALPHA1 = 16.31 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .37213
ALPHA1 = 16.35 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .37760
ALPHA1 = 16.38 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .38311
ALPHA1 = 16.41 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .38868
ALPHA1 = 16.45 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .39437
ALPHA1 = 16.48 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .39960
ALPHA1 = 16.52 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .38823
ALPHA1 = 16.55 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .38684
ALPHA1 = 16.58 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .38544
ALPHA1 = 16.62 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .38403
ALPHA1 = 16.65 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .38260
ALPHA1 = 16.68 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .38117
ALPHA1 = 16.72 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .37972
ALPHA1 = 16.75 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .37826
ALPHA1 = 16.79 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .37678
ALPHA1 = 16.82 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .37530
ALPHA1 = 16.85 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .36388
ALPHA1 = 16.89 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .36937
ALPHA1 = 16.92 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .37491
ALPHA1 = 16.96 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .38050

Computer program INVOL3 (cont)

ALPHA1 = 16.99 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .38614
ALPHA1 = 17.02 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .39184
ALPHA1 = 17.06 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .39758
ALPHA1 = 17.09 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .40338
ALPHA1 = 17.12 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .40923
ALPHA1 = 17.16 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .41513
ALPHA1 = 17.19 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .42109
ALPHA1 = 17.23 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .42710
ALPHA1 = 17.26 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .43316
ALPHA1 = 17.29 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .43928
ALPHA1 = 17.33 (DEG)	S1 = 1.0	S2 = 1.0	S3 = -1.0	POINT EFFICIENCY = .44174
ALPHA1 = 17.36 (DEG)	S1 = 1.0	S2 = -1.0	S3 = -1.0	POINT EFFICIENCY = .43973
ALPHA1 = 17.40 (DEG)	S1 = 1.0	S2 = -1.0	S3 = -1.0	POINT EFFICIENCY = .43535
ALPHA1 = 17.43 (DEG)	S1 = 1.0	S2 = -1.0	S3 = -1.0	POINT EFFICIENCY = .43098
ALPHA1 = 17.46 (DEG)	S1 = 1.0	S2 = -1.0	S3 = -1.0	POINT EFFICIENCY = .42664
ALPHA1 = 17.50 (DEG)	S1 = 1.0	S2 = -1.0	S3 = -1.0	POINT EFFICIENCY = .42232
ALPHA1 = 17.53 (DEG)	S1 = 1.0	S2 = -1.0	S3 = -1.0	POINT EFFICIENCY = .41802
ALPHA1 = 17.57 (DEG)	S1 = 1.0	S2 = -1.0	S3 = -1.0	POINT EFFICIENCY = .41375
ALPHA1 = 17.60 (DEG)	S1 = 1.0	S2 = -1.0	S3 = -1.0	POINT EFFICIENCY = .40950
ALPHA1 = 17.63 (DEG)	S1 = 1.0	S2 = -1.0	S3 = -1.0	POINT EFFICIENCY = .40527
ALPHA1 = 17.67 (DEG)	S1 = 1.0	S2 = -1.0	S3 = -1.0	POINT EFFICIENCY = .40106
ALPHA1 = 17.70 (DEG)	S1 = 1.0	S2 = -1.0	S3 = -1.0	POINT EFFICIENCY = .39687
ALPHA1 = 17.73 (DEG)	S1 = 1.0	S2 = -1.0	S3 = 1.0	POINT EFFICIENCY = .38234
ALPHA1 = 17.77 (DEG)	S1 = 1.0	S2 = -1.0	S3 = 1.0	POINT EFFICIENCY = .38552
ALPHA1 = 17.80 (DEG)	S1 = 1.0	S2 = -1.0	S3 = 1.0	POINT EFFICIENCY = .38871
ALPHA1 = 17.84 (DEG)	S1 = 1.0	S2 = -1.0	S3 = 1.0	POINT EFFICIENCY = .39190
ALPHA1 = 17.87 (DEG)	S1 = 1.0	S2 = -1.0	S3 = 1.0	POINT EFFICIENCY = .39509
ALPHA1 = 17.90 (DEG)	S1 = 1.0	S2 = -1.0	S3 = 1.0	POINT EFFICIENCY = .39828
ALPHA1 = 17.94 (DEG)	S1 = 1.0	S2 = -1.0	S3 = 1.0	POINT EFFICIENCY = .40147
ALPHA1 = 17.97 (DEG)	S1 = 1.0	S2 = -1.0	S3 = 1.0	POINT EFFICIENCY = .40466
ALPHA1 = 18.01 (DEG)	S1 = 1.0	S2 = -1.0	S3 = 1.0	POINT EFFICIENCY = .40786
ALPHA1 = 18.04 (DEG)	S1 = 1.0	S2 = -1.0	S3 = 1.0	POINT EFFICIENCY = .41105
ALPHA1 = 18.07 (DEG)	S1 = 1.0	S2 = -1.0	S3 = 1.0	POINT EFFICIENCY = .41425
ALPHA1 = 18.11 (DEG)	S1 = 1.0	S2 = -1.0	S3 = 1.0	POINT EFFICIENCY = .41744
ALPHA1 = 18.14 (DEG)	S1 = 1.0	S2 = -1.0	S3 = 1.0	POINT EFFICIENCY = .42064
ALPHA1 = 18.17 (DEG)	S1 = 1.0	S2 = -1.0	S3 = 1.0	POINT EFFICIENCY = .42384
ALPHA1 = 18.21 (DEG)	S1 = 1.0	S2 = -1.0	S3 = -1.0	POINT EFFICIENCY = .42346
ALPHA1 = 18.24 (DEG)	S1 = 1.0	S2 = -1.0	S3 = -1.0	POINT EFFICIENCY = .41918
ALPHA1 = 18.28 (DEG)	S1 = 1.0	S2 = -1.0	S3 = -1.0	POINT EFFICIENCY = .41492
ALPHA1 = 18.31 (DEG)	S1 = 1.0	S2 = -1.0	S3 = -1.0	POINT EFFICIENCY = .41068
ALPHA1 = 18.34 (DEG)	S1 = 1.0	S2 = -1.0	S3 = -1.0	POINT EFFICIENCY = .40647
ALPHA1 = 18.38 (DEG)	S1 = 1.0	S2 = -1.0	S3 = -1.0	POINT EFFICIENCY = .40228
ALPHA1 = 18.41 (DEG)	S1 = 1.0	S2 = -1.0	S3 = -1.0	POINT EFFICIENCY = .39811
ALPHA1 = 18.45 (DEG)	S1 = 1.0	S2 = -1.0	S3 = -1.0	POINT EFFICIENCY = .39396
ALPHA1 = 18.48 (DEG)	S1 = 1.0	S2 = -1.0	S3 = -1.0	POINT EFFICIENCY = .38983
ALPHA1 = 18.51 (DEG)	S1 = 1.0	S2 = 1.0	S3 = -1.0	POINT EFFICIENCY = .37024
ALPHA1 = 18.55 (DEG)	S1 = 1.0	S2 = 1.0	S3 = -1.0	POINT EFFICIENCY = .36884
ALPHA1 = 18.58 (DEG)	S1 = 1.0	S2 = 1.0	S3 = -1.0	POINT EFFICIENCY = .36742
ALPHA1 = 18.61 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .36624
ALPHA1 = 18.65 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .36167
ALPHA1 = 18.68 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .36714
ALPHA1 = 18.72 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .37267
ALPHA1 = 18.75 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .37825
ALPHA1 = 18.78 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .38387
ALPHA1 = 18.82 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .38955
ALPHA1 = 18.85 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .39529
ALPHA1 = 18.89 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .40107
ALPHA1 = 18.92 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .40690
ALPHA1 = 18.95 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .41279
ALPHA1 = 18.99 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .41873
ALPHA1 = 19.02 (DEG)	S1 = 1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .42473

Computer program INVOI3 (cont)

ALPHA:	=	19.05	(DEG)	S1	=	1.0	S2	=	1.0	S3	=	1.0	POINT	EFFICIENCY	=	.43077
ALPHA1	=	19.09	(DEG)	S1	=	1.0	S2	=	1.0	S3	=	-1.0	POINT	EFFICIENCY	=	.43329
ALPHA2	=	19.12	(DEG)	S1	=	1.0	S2	=	1.0	S3	=	-1.0	POINT	EFFICIENCY	=	.43683
ALPHA3	=	19.16	(DEG)	S1	=	1.0	S2	=	1.0	S3	=	-1.0	POINT	EFFICIENCY	=	.43013
ALPHA4	=	19.19	(DEG)	S1	=	1.0	S2	=	1.0	S3	=	-1.0	POINT	EFFICIENCY	=	.42856
ALPHA5	=	19.22	(DEG)	S1	=	1.0	S2	=	1.0	S3	=	-1.0	POINT	EFFICIENCY	=	.42698
ALPHA6	=	19.26	(DEG)	S1	=	1.0	S2	=	1.0	S3	=	-1.0	POINT	EFFICIENCY	=	.42538
ALPHA7	=	19.29	(DEG)	S1	=	1.0	S2	=	1.0	S3	=	-1.0	POINT	EFFICIENCY	=	.42377
ALPHA8	=	19.33	(DEG)	S1	=	1.0	S2	=	1.0	S3	=	-1.0	POINT	EFFICIENCY	=	.42215
ALPHA9	=	19.36	(DEG)	S1	=	1.0	S2	=	1.0	S3	=	-1.0	POINT	EFFICIENCY	=	.42052
ALPHA10	=	19.39	(DEG)	S1	=	1.0	S2	=	1.0	S3	=	-1.0	POINT	EFFICIENCY	=	.41887
ALPHA11	=	19.43	(DEG)	S1	=	1.0	S2	=	1.0	S3	=	-1.0	POINT	EFFICIENCY	=	.41721
ALPHA12	=	19.46	(DEG)	S1	=	1.0	S2	=	1.0	S3	=	-1.0	POINT	EFFICIENCY	=	.41554
ALPHA13	=	19.50	(DEG)	S1	=	1.0	S2	=	1.0	S3	=	-1.0	POINT	EFFICIENCY	=	.40300
ALPHA14	=	19.53	(DEG)	S1	=	1.0	S2	=	1.0	S3	=	-1.0	POINT	EFFICIENCY	=	.40896
ALPHA15	=	19.55	(DEG)	S1	=	1.0	S2	=	1.0	S3	=	-1.0	POINT	EFFICIENCY	=	.41495
ALPHA16	=	19.58	(DEG)	S1	=	1.0	S2	=	1.0	S3	=	-1.0	POINT	EFFICIENCY	=	.42105
ALPHA17	=	19.60	(DEG)	S1	=	1.0	S2	=	1.0	S3	=	-1.0	POINT	EFFICIENCY	=	.42717
ALPHA18	=	19.63	(DEG)	S1	=	1.0	S2	=	1.0	S3	=	-1.0	POINT	EFFICIENCY	=	.43335
ALPHA19	=	19.65	(DEG)	S1	=	1.0	S2	=	1.0	S3	=	-1.0	POINT	EFFICIENCY	=	.43958
ALPHA20	=	19.70	(DEG)	S1	=	1.0	S2	=	1.0	S3	=	-1.0	POINT	EFFICIENCY	=	.44587
ALPHA21	=	19.72	(DEG)	S1	=	1.0	S2	=	1.0	S3	=	-1.0	POINT	EFFICIENCY	=	.45222
ALPHA22	=	19.77	(DEG)	S1	=	1.0	S2	=	1.0	S3	=	-1.0	POINT	EFFICIENCY	=	.45862
ALPHA23	=	19.80	(DEG)	S1	=	1.0	S2	=	1.0	S3	=	-1.0	POINT	EFFICIENCY	=	.46508
ALPHA24	=	19.83	(DEG)	S1	=	1.0	S2	=	1.0	S3	=	-1.0	POINT	EFFICIENCY	=	.47160
ALPHA25	=	19.87	(DEG)	S1	=	1.0	S2	=	1.0	S3	=	-1.0	POINT	EFFICIENCY	=	.47775
ALPHA26	=	19.90	(DEG)	S1	=	1.0	S2	=	-1.0	S3	=	1.0	POINT	EFFICIENCY	=	.48137
ALPHA27	=	19.94	(DEG)	S1	=	1.0	S2	=	-1.0	S3	=	1.0	POINT	EFFICIENCY	=	.48508
ALPHA28	=	19.97	(DEG)	S1	=	1.0	S2	=	-1.0	S3	=	-1.0	POINT	EFFICIENCY	=	.47621
ALPHA29	=	20.00	(DEG)	S1	=	1.0	S2	=	-1.0	S3	=	-1.0	POINT	EFFICIENCY	=	.46675
ALPHA30	=	20.04	(DEG)	S1	=	1.0	S2	=	-1.0	S3	=	-1.0	POINT	EFFICIENCY	=	.46206
ALPHA31	=	20.07	(DEG)	S1	=	1.0	S2	=	-1.0	S3	=	-1.0	POINT	EFFICIENCY	=	.45739
ALPHA32	=	20.10	(DEG)	S1	=	1.0	S2	=	-1.0	S3	=	-1.0	POINT	EFFICIENCY	=	.45275
ALPHA33	=	20.14	(DEG)	S1	=	1.0	S2	=	-1.0	S3	=	-1.0	POINT	EFFICIENCY	=	.4

Computer program INVOL3 (cont)

ALPHA1 = 21.12 (DEG)	S1 = -1.0	S2 = 1.0	S3 = -1.0	POINT EFFICIENCY = .40586
ALPHA1 = 21.15 (DEG)	S1 = -1.0	S2 = 1.0	S3 = -1.0	POINT EFFICIENCY = .40348
ALPHA1 = 21.19 (DEG)	S1 = -1.0	S2 = 1.0	S3 = -1.0	POINT EFFICIENCY = .39870
ALPHA1 = 21.22 (DEG)	S1 = -1.0	S2 = 1.0	S3 = -1.0	POINT EFFICIENCY = .39586
ALPHA1 = 21.26 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .39083
ALPHA1 = 21.29 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .38584
ALPHA1 = 21.32 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .38088
ALPHA1 = 21.36 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .37595
ALPHA1 = 21.39 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .37106
ALPHA1 = 21.43 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .36621
ALPHA1 = 21.46 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .36138
ALPHA1 = 21.49 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .35659
ALPHA1 = 21.53 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .35184
ALPHA1 = 21.56 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .34712
ALPHA1 = 21.59 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .34243
ALPHA1 = 21.63 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .33778
ALPHA1 = 21.66 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .33317
ALPHA1 = 21.70 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .32857
ALPHA1 = 21.73 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .32397
ALPHA1 = 21.76 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .31937
ALPHA1 = 21.80 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .31478
ALPHA1 = 21.83 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .31018
ALPHA1 = 21.87 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .30559
ALPHA1 = 21.90 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .30100
ALPHA1 = 21.93 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .29641
ALPHA1 = 21.97 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .29182
ALPHA1 = 22.00 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .28723
ALPHA1 = 22.03 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .28264
ALPHA1 = 22.07 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .27805
ALPHA1 = 22.10 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .27346
ALPHA1 = 22.14 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .26887
ALPHA1 = 22.17 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .26428
ALPHA1 = 22.20 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .25969
ALPHA1 = 22.24 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .25510
ALPHA1 = 22.27 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .25051
ALPHA1 = 22.31 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .24592
ALPHA1 = 22.34 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .24133
ALPHA1 = 22.37 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .23674
ALPHA1 = 22.41 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .23215
ALPHA1 = 22.44 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .22756
ALPHA1 = 22.47 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .22297
ALPHA1 = 22.51 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .21838
ALPHA1 = 22.54 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .21379
ALPHA1 = 22.58 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .20920
ALPHA1 = 22.61 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .20461
ALPHA1 = 22.64 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .20002
ALPHA1 = 22.68 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .19543
ALPHA1 = 22.71 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .19084
ALPHA1 = 22.75 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .18625
ALPHA1 = 22.78 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .18166
ALPHA1 = 22.81 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .17707
ALPHA1 = 22.85 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .17248
ALPHA1 = 22.88 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .16789
ALPHA1 = 22.92 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .16330
ALPHA1 = 22.95 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .15871
ALPHA1 = 22.98 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .15412
ALPHA1 = 23.02 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .14953
ALPHA1 = 23.05 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .14494
ALPHA1 = 23.08 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .14035
ALPHA1 = 23.12 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .13576
ALPHA1 = 23.15 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .13117

Computer program INVOL3 (cont)

ALPHA1 = 23.19 (DEG)	S1 = -1.0	S2 = -1.0	S3 = 1.0	POINT EFFICIENCY = .40583
ALPHA1 = 23.22 (DEG)	S1 = -1.0	S2 = -1.0	S3 = 1.0	POINT EFFICIENCY = .40818
ALPHA1 = 23.25 (DEG)	S1 = -1.0	S2 = -1.0	S3 = 1.0	POINT EFFICIENCY = .41053
ALPHA1 = 23.29 (DEG)	S1 = -1.0	S2 = -1.0	S3 = 1.0	POINT EFFICIENCY = .41286
ALPHA1 = 23.32 (DEG)	S1 = -1.0	S2 = -1.0	S3 = 1.0	POINT EFFICIENCY = .41519
ALPHA1 = 23.36 (DEG)	S1 = -1.0	S2 = -1.0	S3 = 1.0	POINT EFFICIENCY = .41750
ALPHA1 = 23.39 (DEG)	S1 = -1.0	S2 = -1.0	S3 = 1.0	POINT EFFICIENCY = .41981
ALPHA1 = 23.42 (DEG)	S1 = -1.0	S2 = -1.0	S3 = 1.0	POINT EFFICIENCY = .42210
ALPHA1 = 23.46 (DEG)	S1 = -1.0	S2 = -1.0	S3 = 1.0	POINT EFFICIENCY = .42439
ALPHA1 = 23.49 (DEG)	S1 = -1.0	S2 = -1.0	S3 = -1.0	POINT EFFICIENCY = .42309
ALPHA1 = 23.52 (DEG)	S1 = -1.0	S2 = -1.0	S3 = -1.0	POINT EFFICIENCY = .41790
ALPHA1 = 23.56 (DEG)	S1 = -1.0	S2 = -1.0	S3 = -1.0	POINT EFFICIENCY = .41275
ALPHA1 = 23.59 (DEG)	S1 = -1.0	S2 = 1.0	S3 = -1.0	POINT EFFICIENCY = .39138
ALPHA1 = 23.62 (DEG)	S1 = -1.0	S2 = 1.0	S3 = -1.0	POINT EFFICIENCY = .38914
ALPHA1 = 23.66 (DEG)	S1 = -1.0	S2 = 1.0	S3 = -1.0	POINT EFFICIENCY = .38689
ALPHA1 = 23.69 (DEG)	S1 = -1.0	S2 = 1.0	S3 = -1.0	POINT EFFICIENCY = .38464
ALPHA1 = 23.73 (DEG)	S1 = -1.0	S2 = 1.0	S3 = -1.0	POINT EFFICIENCY = .38239
ALPHA1 = 23.76 (DEG)	S1 = -1.0	S2 = 1.0	S3 = -1.0	POINT EFFICIENCY = .38012
ALPHA1 = 23.80 (DEG)	S1 = -1.0	S2 = 1.0	S3 = -1.0	POINT EFFICIENCY = .37786
ALPHA1 = 23.83 (DEG)	S1 = -1.0	S2 = 1.0	S3 = -1.0	POINT EFFICIENCY = .37559
ALPHA1 = 23.86 (DEG)	S1 = -1.0	S2 = 1.0	S3 = -1.0	POINT EFFICIENCY = .37331
ALPHA1 = 23.90 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .36117
ALPHA1 = 23.93 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .36584
ALPHA1 = 23.96 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .37055
ALPHA1 = 24.00 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .37529
ALPHA1 = 24.03 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .38006
ALPHA1 = 24.07 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .38485
ALPHA1 = 24.10 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .38969
ALPHA1 = 24.13 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .39455
ALPHA1 = 24.17 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .39944
ALPHA1 = 24.20 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .40437
ALPHA1 = 24.24 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .40933
ALPHA1 = 24.27 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .41432
ALPHA1 = 24.30 (DEG)	S1 = -1.0	S2 = 1.0	S3 = 1.0	POINT EFFICIENCY = .41935
ALPHA1 = 24.34 (DEG)	S1 = -1.0	S2 = 1.0	S3 = -1.0	POINT EFFICIENCY = .42441
ALPHA1 = 24.37 (DEG)	S1 = -1.0	S2 = 1.0	S3 = -1.0	POINT EFFICIENCY = .42590
ALPHA1 = 24.40 (DEG)	S1 = -1.0	S2 = 1.0	S3 = -1.0	POINT EFFICIENCY = .42346
ALPHA1 = 24.44 (DEG)	S1 = -1.0	S2 = 1.0	S3 = -1.0	POINT EFFICIENCY = .42101
ALPHA1 = 24.47 (DEG)	S1 = -1.0	S2 = 1.0	S3 = -1.0	POINT EFFICIENCY = .41856
ALPHA1 = 24.51 (DEG)	S1 = -1.0	S2 = 1.0	S3 = -1.0	POINT EFFICIENCY = .41611

CYCLE EFFICIENCY = .414

REFERENCE

- A-1 G.G. Lowen, City College of N.Y., and F.R. Tepper, ARRADCOM, "Fuze Gear Train Analysis," Technical Report ARLCD-TR-79030, ARRADCOM, Dover, NJ, December 1979.

APPENDIX B
COMPUTER PROGRAM INVOL4 (REVISED)

The original program descriptions were given in appendix C of Fuze Gear Train Analysis (ref B-1). The following appendix contains revised descriptions, listings and sample outputs of computer program INVOL4, which computes point and cycle efficiencies for two pass involute gear trains in a spin environment. All meshes have unity contact ratio.

The following changes were made:

1. The diametral pitches of both meshes are given as data and are printed in the output.
2. The numbers of teeth of both meshes are given as data and are printed in the output.
3. The initialization parameters J (one for each of the two meshes) are introduced. They are given as part of the data and are printed in the output. Again, these parameters allow the arbitrary choice of the initial point of contact of a given mesh anywhere within the range of possible contact points.

In addition to these changes, it contains gear computations (according to program INVOL1) which are necessary to give the two pass step-up gear train the same overall gear ratio as that of the three pass step-up gear train.

The program INVOL4 is based on appendix A (ref B-1) which derives the moment input-output relationship for a two pass step-up gear train, operating in a spin environment. Here again, all meshes have unity contact ratio. INVOL4 is very similar to INVOL3 in its construction. Again, the expressions for the contact geometry and other auxiliary geometric terms may be found in appendix A (ref B-1).

Input Parameters

The following parameters represent the input data for the program. Those which involve gear dimensions only must be obtained from the results of INVOL1 (ref B-1) since the moment expressions are again derived for unity contact ratio only.

PSUBD1	=	P_{d1}
PSUBD2	=	P_{d2}
NG1	=	N_{G1}
NP2	=	N_{P2}
NG2	=	N_{G2}
NP3	=	N_{P3}
MU	=	μ , coefficient of friction at all pivots and at all tooth contact points

RPM, revolutions per minute of the fuze body

CAPRP1 = R_{p1}

CAPRP2 = R_{p2}

RP2 = r_{p2}

RP3 = r_{p3}

THETA1 = θ_1

THETA2 = θ_2

ISTOP arbitrary single digit integer for multiple data sets.
It must be zero for last set of data.

R1 = R_1

R2 = R_2

R3 = R_3

RHO1 = ρ_1

RHO2 = ρ_2

RHO3 = ρ_3

CAPRB1 = R_{b1}

CAPRB2 = R_{b2}

RB2 = r_{b2}

RB3 = r_{b3}

CAPR01 = R_{o1}

CAPR02 = R_{o2}

RO2 = r_{o2}

RO3 = r_{o3}

M1 = m_1 , mass of input gear 1

M2 = m_2 , mass of gear and pinion 2

M3 = m_3 , mass of pinion 3

MD = md^2 , mass-distance product contained in the expression for the input moment M_{in}

K = K_2 , the range divisor which is associated with gear 2, the driving gear of the last mesh for this case (eq A-207, ref B-1)

J1, J2, initialization parameters

Computations

Computation of MIN, Gammas and Betas

To start with, the program computes the input moment

$$MIN = M_{in} = md^2\omega^2 \quad (B-1)$$

The program computes the angles γ_2 , γ_3 and β_1 , β_2 according to the expression given in appendix A (ref B-1).

Determination of the Gear Train Constants

The determination of the gear train constants consists of the following:

RATIO = K_{RATIO} (eq 2, ref B-1). Since the angular velocity is constant, this parameter may be expressed in terms of the applicable base radii, i.e.,

$$\frac{R_{b1} \times R_{b2}}{r_{b2} \times r_{b3}}$$

TEST1 and TEST2 represent the tangent functions of the mesh pressure angles, which are used in conjunction with the values of the signum functions s.

D1 and D2 are given by equations A-204 and A-217 (ref B-1), respectively, and represent the distances between the points of tangency to the base circles along the lines of action of the two meshes.

MTOT = 0 represents the initialization of the sum of the output moments. This is used for the determination of the cycle efficiency.

Determination of Earliest and Latest Possible
Values of ALPHAS, Initialization of ALPHAS.
Centrifugal Forces

The determination of the earliest and latest possible angles of rotation is accomplished with the help of subroutine ALPHA, at the end of the program, which makes use of equations A-205, A-206, A-218, and A-219 (ref B-1). The angles of initial contact α_1 are determined with the help of the initialization parameters J_1 according to:

$$\alpha_i = \alpha_{iIN} + J_i(\alpha_{iFIN} - \alpha_{iIN}) \quad (i=1,2) \quad (B-2)$$

The additional parameter J_3 serves to distinguish between the two possible contact conditions of mesh no. 1. $J_3 = 0$ while the first set of teeth is in contact. $J_3 = 1$ when the latest possible value of α_1 has been reached and contact is transferred to the second set of teeth. $J_3 = 0$ at all times when $J_1 = 0$, i.e., contact is made in mesh no. 1 at the earliest possible time, and therefore, contact need never be transferred to the second set of teeth to obtain a complete contact cycle (cards no. 93 and 106).

The angular increments of gears 2 and 1, i.e., DELAL2 and DELAL1, are determined with the help of equations A-207 and A-208 (ref B-1), respectively.

The centrifugal forces, which act on the pivots of the various gear and/or pinion assemblies, are obtained by way of equations A-131, A-154, and A-178 (ref B-1).

Point and Cycle Efficiencies

Both point and cycle efficiencies are based on equations A-193 (ref B-1) for the output moment $M_{O3} = M_{O3}$.

The point efficiency is computed directly in the manner of equation 3 (ref B-1) i.e.,

$$\epsilon_p = K_{RATIO} \frac{M_{O3}}{M_{in}} = \text{POINTEF} \quad (B-3)$$

The cycle efficiency is treated in the manner of equation A-3 of appendix A, i.e.,

$$\epsilon_c = \frac{K_{RATIO} \Delta \alpha_1 M_{O3}}{M_{in} (\alpha_{1FIN} - \alpha_{1IN})} = \text{CYCLEFF} \quad (B-4)$$

The program gives the summation as

$$MTOT = \sum_{o3}$$

(B-5)

Gear Train Motion Model

The simulation of the gear train motion, which is necessary for the computation of both POINTEF and CYCLEFF, is found in a loop which begins with statement label no. 14 (card no. 105) and ends with card no. 171.

The motions of the individual driving gears are initialized with the help of the parameters J_1 and J_2 . The position of each mesh is subsequently incremented by the appropriate DELAL1 and DELAL2. Whenever the J_i 's ($i=1,2$) are not equal to zero, and one of the angles α_{iFIN} has been reached, the particular mesh is reset to its respective angle α_{iIN} . Since mesh 2 goes through a number of cycles while mesh 1 goes through one cycle, mesh 2 has to be reset to its starting position AL2IN once the angle AL2FIN has been reached. This is accomplished by the conditional statement on card no. 105. When $J_1 = 0$, i.e., contact in mesh 1 is made at the earliest possible point, CYCLEFF is determined and the computation is ended once the angle AL1FIN - DELAL1 is reached. When $J_1 \neq 0$, the above occurs when ALPHA1 reaches the magnitude of its initial angle minus DELAL1. (The nature of the numerical integration requires that only K computations be included.)

The values of the signum functions s_1 and s_2 are determined continuously according to equations A-216 and A-222 (ref B-1).

The instantaneous distances to the contact points, i.e., $A1 = a_1$ and $A2 = a_2$, are determined for each of the meshes by appropriate adaptations of equation A-203 (ref B-1) (also equations A-214 and A-220 (ref B-1)).

The determination of the instantaneous output moment $M03 = M_{o3}$ requires the continuous computation of the variable quantities A_1 to A_{14} , C_1 to C_4 and D_1 to D_3 , which are given originally in conjunction with the various equilibrium conditions in appendix A (ref B-1). The program uses the following nomenclature for these variables:

AA1 to AA14

CC1 to CC4

DD1 to DD3

Output

The output of the program is again best explained with the help of the sample computation shown at the end of the program. This example uses the gear data with the help of computer program INVOL1. The output lists the following:

Input Parameters

Mesh No. 1

CAPRP1	=	R_{p1}	=	0.55000 in. (1.3970 cm)	PSUBD1	=	P_{d1}	=	50
CAPRB1	=	R_{b1}	=	0.51683 in. (1.3127 cm)	NG1	=	N_{G1}	=	55
CAPRO1	=	R_{o1}	=	0.55936 in. (1.4208 cm)	NP2	=	N_{p2}	=	8
RP2	=	r_{p2}	=	0.08000 in. (0.2032 cm)	J1	=	0		
RB2	=	r_{b2}	=	0.07518 in. (0.1910 cm)					
RO2	=	r_{o2}	=	0.09655 in. (0.2452 cm)	(This is a ROFIN as given by INVOL1.)				

Also,

$$\text{THETA1} = \theta_1 = 20^\circ$$

Mesh No. 2

CAPRP2	=	R_{p2}	=	0.39286 in. (0.9979 cm)	PSUBD2	=	P_{d2}	=	70
CAPRB2	=	R_{b2}	=	0.36916 in. (0.9377 cm)	NG2	=	N_{G2}	=	55
CAPRO2	=	R_{o2}	=	0.39954 in. (1.0148 cm)	NP3	=	N_{p3}	=	8
RP3	=	r_{p3}	=	0.05714 in. (0.1451 cm)	J2	=	0		
RB3	=	r_{b3}	=	0.05370 in. (0.1364 cm)					
RO3	=	r_{o3}	=	0.06898 in. (0.1752 cm)					

Also,

$$\text{THETA2} = \theta_2 = 20^\circ$$

In addition,

MU	=	μ	=	0.2
RPM	=	1000		
M1	=	m_1	=	$0.12 \times 10^{-3} \text{ lb-sec}^2/\text{in.}$ ($2.101 \times 10^{-2} \text{ kg}$)
M2	=	m_2	=	$0.253 \times 10^{-4} \text{ lb-sec}^2/\text{in.}$ ($4.430 \times 10^{-3} \text{ kg}$)
M3	=	m_3	=	$0.153 \times 10^{-5} \text{ lb-sec}^2/\text{in.}$ ($2.679 \times 10^{-4} \text{ kg}$)

$R_1 = R_1 = 0.225 \text{ in. (0.5715 cm)}$
 $R_2 = R_2 = 0.497 \text{ in. (1.2624 cm)}$
 $R_3 = R_3 = 0.640 \text{ in. (1.6256 cm)}$
 $RHO1 = \rho_1 = 0.062 \text{ in. (0.1575 cm)}$
 $RHO2 = \rho_2 = 0.025 \text{ in. (0.0635 cm)}$
 $RHO3 = \rho_3 = 0.018 \text{ in. (0.0457 cm)}$
 $MD = md^2 = 0.275 \times 10^{-5} \text{ lb-sec}^2\text{-in. (3.105} \times 10^{-7} \text{ kg-m}^2)$
 $K = 25$

Computed Values

The point efficiency is given as a function of the angle α_1 , together with the signum parameters s_1 and s_2 (given for checking purposes). The cycle efficiency is shown at the end of the output. In addition, the input moment MIN is printed out.

Use of Computer Program INVOLL to Obtain Unity Contact Ratio Parameters for Both Meshes

The following gives the outputs of computer program INVOLL (app A, ref B-1) for the present two pass step-up gear mesh with a total step-up ratio of $(55/8) \times (55/8) = 47.265$. The above is essentially the same as the gear ratio of the three pass gear train of appendix A.

Output of computer program INVOLI

D1METRAL PITCH (PSMRD) = 50.00
 GEAR NUMBER OF TEETH (NG) = 55
 PINION NUMBER OF TEETH (NP) = 8
 PRESSURE ANGLE (THETA) = 20.00
 GEAR PITCH RADIUS (CAPRP) = .55080 PINION PITCH RADIUS (RP) = .08888
 GEAR BASE RADIUS (CAPRB) = .51683 PINION BASE RADIUS (RB) = .07518
 STANDARD TOOTH THICKNESS AT PITCH RADIUS (TSTAND) = .03142
 MIN WITHDRAWAL DISTANCE (CI) = .01064
 GEAR BLANK RADIUS (CAPRO) = .55936 ORIGINAL PINION BLANK RADIUS (RO) = .11064
 ORIGINAL CONTACT RATIO (CRATIO) = 1.349
 PINION OUTSIDE RADIUS FOR UNITY CONTACT RATIO (ROFIN) = .09655
 FINAL CONTACT RATIO (CRFIN) = 1.000
 GEAR TOOTH THICKNESS AT PITCH CIRCLE (CAPTC) = .02367 PINION TOOTH THICKNESS AT PITCH CIRCLE (TC) = .03916
 GEAR PRESSURE ANGLE AT OUTSIDE RADIUS (THEO6D) = 22.48626 PINION PRESSURE ANGLE AT FINAL OUTSIDE RADIUS (THEOPD) = 38.84456
 GEAR TOOTH THICKNESS AT OUTSIDE RADIUS (CAPTO) = .01572 PINION TOOTH THICKNESS AT FINAL OUTSIDE RADIUS (TO) = .02551
 GEAR TOOTH THICKNESS AT BASE CIRCLE (CAPTB) = .03765 THEORETICAL PINION TOOTH THICKNESS AT BASE CIRCLE (TB) = .03984
 RADIUS OF ROOT CIRCLE OF GEAR (CAPROOT) = .51622 MINIMUM ALLOWABLE RADIUS OF ROOT CIRCLE OF GEAR (CAPRMIN) = .48368
 THE GEAR IS NOT UNDERCUT
 RADIUS OF ROOT CIRCLE OF PINION (ROOT) = .06750

Output of computer program INVOLL (cont)

DIAMETRAL PITCH (PSUMD) = 70.00
 GEAR NUMBER OF TEETH (NG) = 55
 PINION NUMBER OF TEETH (NP) = 8
 PRESSURE ANGLE (THETA) = 20.00
 GEAR PITCH RADIUS (CAPRP) = .30286 PINION PITCH RADIUS (RP) = .05714
 GEAR BASE RADIUS (CAPRB) = .36916 PINION BASE RADIUS (RB) = .05370
 STANDARD TOOTH THICKNESS AT PITCH RADIUS (TSTAND) = .02244
 MIN WITHDRAWAL DISTANCE (C) = .00768
 GEAR BLANK RADIUS (CAPRO) = .39954 ORIGINAL PINION BLANK RADIUS (RO) = .07903
 ORIGINAL CONTACT RATIO (CRATIO) = 1.349
 PINION OUTSIDE RADIUS FOR UNITY CONTACT RATIO (DOFIN) = .06096
 FINAL CONTACT RATIO (CRFIN) = 1.000
 GEAR TOOTH THICKNESS AT PITCH CIRCLE (CAPTC) = .01691 PINION TOOTH THICKNESS AT PITCH CIRCLE (TC) = .02797
 GEAR PRESSURE ANGLE AT OUTSIDE RADIUS (THEO6D) = 22.49626 PINION PRESSURE ANGLE AT FINAL OUTSIDE RADIUS (THEOPD) = 38.86456
 GEAR TOOTH THICKNESS AT OUTSIDE RADIUS (CAPTO) = .01195 PINION TOOTH THICKNESS AT FINAL OUTSIDE RADIUS (TO) = .01822
 GEAR TOOTH THICKNESS AT BASE CIRCLE (CAPTB) = .02689 THEORETICAL PINION TOOTH THICKNESS AT BASE CIRCLE (TB) = .02789
 RADIUS OF ROOT CIRCLE OF GEAR (CAPROOT) = .36873 MINIMUM ALLOWABLE RADIUS OF ROOT CIRCLE OF GEAR (CAPMIN) = .34543
 THE GEAR IS NOT UNDERCUT
 RADIUS OF ROOT CIRCLE OF PINION (ROOT) = .04627

Computer program INVOL4

PROGRAM INVOL4 74/74 OPT=1 FTN 4.8-508 04/15/81 10.35.05 PAGE 1

```

1      PROGRAM INVOL4(INPUT,OUTPUT,TAPES=INPUT,TAPES=OUTPUT)
C
C POINT AND CYCLE EFFICIENCIES FOR TWO PASS INVOLUTE STEP-UP GEAR TRAIN
C IN SPIN ENVIRONMENT (ALL MESHES HAVE UNITY CONTACT RATIO)
C
5      REAL MIN,MU,M1,M2,M3,M03,M0T,M0,J1,J2,MG1,MG2,MG3,M03
C
C READ AND WRITE INPUT DATA
C
10     READ(5,1)PSUBD1,PSUBD2,MG1,MG2,MG3,MU,RPM,CAPRP1,CAPRP2,RP2,
      RP3,THETA1,THETA2,ISTOP
      READ(5,2)R1,R2,R3
      READ(5,3)RHO1,RHO2,RHO3
      READ(5,4)CAPRP1,CAPRP2,RP2,RP3
      READ(5,5)CAPRP1,CAPRP2,RP2,RP3
      READ(5,6)M1,M2,M3
      READ(5,7)M0,K,J1,J2
      1 FORMAT(2F10.4,4F10.0,F10.3,F10.0/4F10.5/2F10.4/11)
      2 FORMAT(3F10.5)
      3 FORMAT(3F10.5)
      4 FORMAT(4F10.5)
      5 FORMAT(4F10.5)
      6 FORMAT(3E10.4)
      7 FORMAT(1E10.4/13/2F10.2)
      PI = 3.14159
      OMEGA = RPM*2.*PI/60.
      OM2 = OMEGA*OMEGA
C
C COMPUTATION OF MIN, GAMMAS AND BETAS
C
      MIN = M0*OM2
      GAMMA2 = ACOS((R1+R1 + R2+R2 - (CAPRP1+RP2)*(CAPRP1+RP2))/
      1(2.*R1+R2))
      GAMMA3P = ACOS((R2+R2 + R3+R3 - (CAPRP2+RP3)*(CAPRP2+RP3))/
      1(2.*R2+R3))
      GAMMA3 = GAMMA2 + GAMMA3P
      DELTA2 = ACOS(((CAPRP1+RP2)*(CAPRP1+RP2) + R1+R1 - R2+R2)/
      1(2.*R1*(CAPRP1 + RP2)))
      DELTA3 = ACOS(((CAPRP2+RP3)*(CAPRP2+RP3) + R2+R2 - R3+R3)/
      1(2.*R2*(CAPRP2 + RP3)))
      BETA1 = PI - DELTA2
      BETA2 = GAMMA2 + PI - DELTA3
      WRITE(6,8)PSUBD1,PSUBD2,MG1,MG2,MG3,MU,RPM,CAPRP1,CAPRP2,
      1RP2,RP3,THETA1,THETA2
      WRITE(6,9)R1,R2,R3,M1,M2,M3
      WRITE(6,10)RHO1,RHO2,RHO3
      WRITE(6,11)CAPRP1,CAPRP2,RP2,RP3
      WRITE(6,12)CAPRP1,CAPRP2,RP2,RP3
      WRITE(6,13)M0,K,J1,J2
      8 FORMAT(10.5X,PSUBD1 =,F5.0,3X,PSUBD2 =,F5.0/6X,
      10NG1 =,F4.0,3X,MP2 =,F4.0,3X,MP3 =,F4.0,3X,MP3 =,F4.0/6X,
      2 6X,M1 =,E12.5,3X,M2 =,F6.3,3X,M3 =,F6.3,3X,M3 =,F6.0/6X,
      3CAPRP1 =,F8.5,3X,CAPRP2 =,F8.5/6X,RP2 =,F8.5,3X,RP3 =,
      4F8.5/6X,THETA1 =,F8.3,3X,THETA2 =,F8.3/6X,
      9 FORMAT(6X,R1 =,F7.5,3X,R2 =,F7.5,3X,R3 =,F7.5/6X,M1 =,
      1E12.5,3X,M2 =,E12.5,3X,M3 =,E12.5/6X,
      10 FORMAT(6X,RHO1 =,F7.5,3X,RHO2 =,F7.5,3X,RHO3 =,F7.5/6X)

```

Computer program INVOL4 (cont.)

PROGRAM INVOL4 74/74 OPT=1 FTM 4.8-508 04/15/81 10.35.05 PAGE 2

```

11 FORMAT(6X,'CAPR81 =',F7.5,3X,'CAPR82 =',F7.5,3X,'RB2 =',F7.5,3X,
1*RB3 =',F7.5/)
12 FORMAT(6X,'CAPR01 =',F7.5,3X,'CAPR02 =',F7.5,3X,'R02 =',F7.5,3X,
1* R03 =',F7.5/)
13 FORMAT(6X,'WD =',E10.3//6X,'RANGE DIVISOR =',I4//6X,'J1 =',F4.2,3X,
2*J2 =',F4.2//)
C
C CONVERSION TO RADIAN
C
Z = PI/180.
THETA1 = THETA1*Z
THETA2 = THETA2*Z
C
C DETERMINATION OF GEAR TRAIN CONSTANTS
C
RATIO = (CAPR2-CAPR1)/(RB2-RB3)
TEST1 = TAN(THETA1)
TEST2 = TAN(THETA2)
D1 = (CAPR1 + RB2)*TAN(THETA1)
D2 = (CAPR2 + RB3)*TAN(THETA2)
MTOT = 0.
C
C DETERMINATION OF EARLIEST AND LATEST POSSIBLE VALUES OF ALPHAS
C
CALL ALPHA(CAPR1,RB2,THETA1,CAPR01,R02,AL1IN,AL1FIN)
CALL ALPHA(CAPR2,RB3,THETA2,CAPR02,R03,AL2IN,AL2FIN)
C
DELA2 = (AL2FIN - AL2IN)/K
DELA1 = DELA2-R52/CAPR81
C
C INITIALIZATION OF ALPHAS
C
ALPHA1 = AL1IN + (AL1FIN-AL1IN)*J1
ALPHA2 = AL2IN + (AL2FIN-AL2IN)*J2
ALPHI1 = ALPHA1
J3 = 0
C
C CENTRIFUGAL FORCES
C
T1 = M1*R1-OM2
T2 = M2*R2-OM2
T3 = M3*R3-OM2
C
DENOM = 1. + MU*BU
C
C UPDATE VALUES OF ALPHAS
C
14 IF(ALPHA2 -GT. AL2FIN)ALPHA2 = AL2IN
IF(ALPHA1 -GT.AL1FIN)J3=1
IF(ALPHA1 -GT.AL1FIN)ALPHA1=AL1IN
C
C TEST TO DETERMINE IF CONTACT POINT IS IN APPROACH OR RECESS
C
IF APPROACH, S = 1.
IF RECESS, S = -1.
AT PITCH POINT, S = 0.
C
IF(ALPHA1 -LT. TEST1)S1 = 1.

```

Computer program INVOLA (cont)

PROGRAM INVOLA 74/74 OPT=1 FIN 4.8*508 04/15/81 10.35.05 PAGE 3

```

115 IF(ALPHA2 .LT. TEST2)S2 = 1.
    IF(ALPHA1 .GT. TEST1)S1 = -1.
    IF(ALPHA2 .GT. TEST2)S2 = -1.
    IF(ALPHA1 .EQ. TEST1)S1 = 0.
    IF(ALPHA2 .EQ. TEST2)S2 = 0.

120 C DETERMINATION OF INPUT FOR MOMENT EXPRESSIONS
    C
    A1 = ALPHA1+CAPR81
    A2 = ALPHA2+CAPR82
    AA1 = ABS((1.+MU*MU*S2)*COS(BETA2-THETA2) + MU*(S2-1.))*
    1SIN(BETA2-THETA2))/DENOM
    AA2 = ABS((SIN(GAMMA3) + MU*COS(GAMMA3))/DENOM)
    AA3 = ABS((1.+MU*MU*S2)*SIN(BETA2-THETA2) + MU*(1.-S2)*COS(BETA2
    1-THETA2))/DENOM
    AA4 = ABS((MU*(1.-S1)*SIN(GAMMA3) - COS(GAMMA3))/DENOM)
    AA5 = ABS((MU*(1.-S1)*SIN(BETA1+THETA1) + (1.-S1)*MU*MU)*
    1COS(BETA1+THETA1))/DENOM
    AA6 = ABS((SIN(GAMMA2) - MU*COS(GAMMA2))/DENOM)
    AA7 = ABS((MU*(1.+S2)*SIN(BETA2-THETA2) + (1.-MU*MU*S2)*
    1COS(BETA2-THETA2))/DENOM)
    AA8 = ABS((MU*(1.-S1)*COS(BETA1-THETA1) - (1.-MU*MU*S1)*
    1SIN(BETA1+THETA1))/DENOM)
    AA9 = ABS((MU*(1.-S1)*SIN(GAMMA2) + COS(GAMMA2))/DENOM)
    AA10 = ABS((1.-MU*MU*S2)*SIN(BETA2-THETA2) - MU*(1.+S2)*
    1COS(BETA2-THETA2))/DENOM)
    AA11 = ABS((1.-MU*MU*S1)*SIN(BETA1+THETA1) + MU*(1.+S1)*
    1COS(BETA1+THETA1))/DENOM)
    AA12 = 1./DENOM
    AA13 = ABS((MU*(1.+S1)*SIN(BETA1+THETA1) - (1.-MU*MU*S1)*
    1COS(BETA1+THETA1))/DENOM)
    AA14 = MU/DENOM
    CCT = MU*RHO3*(A2+AA4)
    CC2 = CAPR82 - MU*(S2-A2-RHO2*(AA7+AA10))
    CC3 = MU*RHO2*(AA6+AA9)
    CC4 = MU*RHO1*(AA12+AA14)
    DD1 = R83 - MU*(S2*(D2-A2)+RHO3*(AA1+AA3))
    DD2 = R82 - MU*(S1*(D1-A1)+RHO2*(AA5+AA8))
    DD3 = CAPR81 - MU*(S1-A1-RHO1*(AA11+AA13))
    ALPHA1D = ALPHA1/Z

155 C OUTPUT MOMENT
    C
    M03 = (DD1-DD2)/(CC2-DD3)*(MIN-T1+CC4) - T2-CC3-DD1/CC2 - T3+CC1
    POINTEP = RATIO*M03/MIN
    WRITE(6,15)ALPHA1D,S1,S2,POINTEP
160 15 FORMAT(6X,'ALPHA1 =',F6.2,3X,'S1 =',F5.1,3X,'S2 =',F5.1,3X,
    1*POINT EFFICIENCY =',F7.5)
    MTDI = MTDI + M03

165 C ADVANCE GEAR TRAIN TO NEXT POSITION
    C
    ALPHA1 = ALPHA1 + DELA1
    IF((J3.EQ.1 .AND. ALPHA1-GT.ALPH11-DELA1) .OR. (J1.EQ.0. .AND.
    1ALPH11-GT.ALPH11-DELA1))GO TO 16
    ALPHA2 = ALPHA2 + DELA1+CAPR81/R82
    GO TO 14
170

```

Computer program INVOL4 (cont)

PROGRAM INVOL4 74/74 QP1=1 FTN 4.8+508 04/15/81 10.35.05 PAGE 4

```

16 CYCLEFF = (RATIO-DELA1*HTOT)/(MIN*(ALFIN-AL1IN))
WRITE(6,17)CYCLEFF
17 FORMAT('0',5X,'CYCLE EFFICIENCY =',F5.3)
IF(ISTOP.NE.0)GO TO 100
STOP
END

```

175

Computer program INVOL4 (cont)

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FTN 4.8+508

SUBROUTINE ALPHA 74/74 OPT=1

```

1      SUBROUTINE ALPHA(CAPRB,RB,THETA,CAPRO,RQ,ALIN,ALFIN)
      C
      C THIS SUBROUTINE COMPUTES THE INITIAL AND FINAL VALUES OF ALPHAS
      C
      ALIN = ((CAPRB + RB)*TAN(THETA) - SORT((RQ*RG - RB*RB))/CAPRB
      ALFIN = SORT(CAPRO*CAPRO - CAPRB*CAPRB)/CAPRB
      RETURN
      END
5

```

Computer program INVOL4 (cont)

```

PSUBD01 = 50. PSUBD02 = 70.
NGT = 55. NP2 = 8. NG2 = 55. NP3 = 8.
MIN = .30157E-01 MU = .200 RPM = 1000.
CAPRP1 = .55000 CAPRP2 = .39286
RP2 = .08000 RP3 = .05714
THETA1 = 20.000 THETA2 = 20.000
R1 = .22500 R2 = .49700 R3 = .64000
R4 = .12000E-03 R2 = .25300E-04 R3 = .15300E-05
RND1 = .06200 RND2 = .02500 RND3 = .01800
CAPRB1 = .51683 CAPRB2 = .36916 R82 = .07518 R83 = .05370
CAPR01 = .55936 CAPR02 = .39954 R02 = .89835 R03 = .06898
MD = .275E-05
RANGE DIVISOR = 25
J1 =0.00 J2 =0.00

ALPHA1 = 17.17 S1 = 1.0 S2 = 1.0 POINT EFFICIENCY = .31414
ALPHA1 = 17.21 S1 = 1.0 S2 = 1.0 POINT EFFICIENCY = .31839
ALPHA1 = 17.25 S1 = 1.0 S2 = 1.0 POINT EFFICIENCY = .32266
ALPHA1 = 17.29 S1 = 1.0 S2 = 1.0 POINT EFFICIENCY = .32695
ALPHA1 = 17.32 S1 = 1.0 S2 = 1.0 POINT EFFICIENCY = .33126
ALPHA1 = 17.36 S1 = 1.0 S2 = 1.0 POINT EFFICIENCY = .33560
ALPHA1 = 17.40 S1 = 1.0 S2 = 1.0 POINT EFFICIENCY = .33995
ALPHA1 = 17.44 S1 = 1.0 S2 = 1.0 POINT EFFICIENCY = .34432
ALPHA1 = 17.48 S1 = 1.0 S2 = 1.0 POINT EFFICIENCY = .34871
ALPHA1 = 17.51 S1 = 1.0 S2 = 1.0 POINT EFFICIENCY = .35313
ALPHA1 = 17.55 S1 = 1.0 S2 = 1.0 POINT EFFICIENCY = .35756
ALPHA1 = 17.59 S1 = 1.0 S2 = 1.0 POINT EFFICIENCY = .36202
ALPHA1 = 17.63 S1 = 1.0 S2 = 1.0 POINT EFFICIENCY = .36649
ALPHA1 = 17.67 S1 = 1.0 S2 = 1.0 POINT EFFICIENCY = .37099
ALPHA1 = 17.71 S1 = 1.0 S2 = 1.0 POINT EFFICIENCY = .37551
ALPHA1 = 17.74 S1 = 1.0 S2 = 1.0 POINT EFFICIENCY = .37985
ALPHA1 = 17.78 S1 = 1.0 S2 = 1.0 POINT EFFICIENCY = .38433
ALPHA1 = 17.82 S1 = 1.0 S2 = 1.0 POINT EFFICIENCY = .38880
ALPHA1 = 17.86 S1 = 1.0 S2 = 1.0 POINT EFFICIENCY = .39327
ALPHA1 = 17.90 S1 = 1.0 S2 = 1.0 POINT EFFICIENCY = .39774
ALPHA1 = 17.93 S1 = 1.0 S2 = 1.0 POINT EFFICIENCY = .40221
ALPHA1 = 17.97 S1 = 1.0 S2 = 1.0 POINT EFFICIENCY = .40668
ALPHA1 = 18.01 S1 = 1.0 S2 = 1.0 POINT EFFICIENCY = .41115
ALPHA1 = 18.05 S1 = 1.0 S2 = 1.0 POINT EFFICIENCY = .41562
ALPHA1 = 18.09 S1 = 1.0 S2 = 1.0 POINT EFFICIENCY = .42009
ALPHA1 = 18.12 S1 = 1.0 S2 = 1.0 POINT EFFICIENCY = .42456
ALPHA1 = 18.16 S1 = 1.0 S2 = 1.0 POINT EFFICIENCY = .42903
ALPHA1 = 18.20 S1 = 1.0 S2 = 1.0 POINT EFFICIENCY = .43350
ALPHA1 = 18.24 S1 = 1.0 S2 = 1.0 POINT EFFICIENCY = .43797
ALPHA1 = 18.28 S1 = 1.0 S2 = 1.0 POINT EFFICIENCY = .44244
ALPHA1 = 18.32 S1 = 1.0 S2 = 1.0 POINT EFFICIENCY = .44691
ALPHA1 = 18.35 S1 = 1.0 S2 = 1.0 POINT EFFICIENCY = .45138

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Computer program INVOLA (cont)

ALPHA1 = 18.39	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .35983
ALPHA1 = 18.43	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .36439
ALPHA1 = 18.47	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .36896
ALPHA1 = 18.51	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .37356
ALPHA1 = 18.54	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .37818
ALPHA1 = 18.58	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .38281
ALPHA1 = 18.62	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .38748
ALPHA1 = 18.66	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .39216
ALPHA1 = 18.70	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .39686
ALPHA1 = 18.73	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .39507
ALPHA1 = 18.77	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .39251
ALPHA1 = 18.81	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .38995
ALPHA1 = 18.85	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .38739
ALPHA1 = 18.89	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .38481
ALPHA1 = 18.92	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .38223
ALPHA1 = 18.96	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .37965
ALPHA1 = 19.00	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .37706
ALPHA1 = 19.04	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .37446
ALPHA1 = 19.08	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .37186
ALPHA1 = 19.12	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .36925
ALPHA1 = 19.15	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .36660
ALPHA1 = 19.19	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .36413
ALPHA1 = 19.23	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .36178
ALPHA1 = 19.27	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .35945
ALPHA1 = 19.31	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .35714
ALPHA1 = 19.34	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .35486
ALPHA1 = 19.38	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .35260
ALPHA1 = 19.42	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .35036
ALPHA1 = 19.46	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .34814
ALPHA1 = 19.50	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .34594
ALPHA1 = 19.53	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .34376
ALPHA1 = 19.57	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .34161
ALPHA1 = 19.61	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .33947
ALPHA1 = 19.65	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .33736
ALPHA1 = 19.69	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .33526
ALPHA1 = 19.73	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .33318
ALPHA1 = 19.76	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .33113
ALPHA1 = 19.80	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .32909
ALPHA1 = 19.84	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .32706
ALPHA1 = 19.88	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .32504
ALPHA1 = 19.92	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .32303
ALPHA1 = 19.95	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .32104
ALPHA1 = 19.99	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .31906
ALPHA1 = 20.03	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .31709
ALPHA1 = 20.07	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .31513
ALPHA1 = 20.11	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .31318
ALPHA1 = 20.14	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .31124
ALPHA1 = 20.18	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .30931
ALPHA1 = 20.22	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .30739
ALPHA1 = 20.26	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .30548
ALPHA1 = 20.30	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .30358
ALPHA1 = 20.34	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .30169
ALPHA1 = 20.37	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .30000
ALPHA1 = 20.41	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .29831
ALPHA1 = 20.45	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .29663
ALPHA1 = 20.49	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .29496
ALPHA1 = 20.53	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .29330
ALPHA1 = 20.56	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .29165
ALPHA1 = 20.60	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .29000
ALPHA1 = 20.64	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .28836
ALPHA1 = 20.68	S1 = 1.0	S2 = 1.0	POINT EFFICIENCY = .28672

Computer program INVOLA (cont)

ALPHA1 = 20.72	S1 = 1.0	S2 = -1.0	POINT EFFICIENCY = 43809
ALPHA1 = 20.75	S1 = 1.0	S2 = -1.0	POINT EFFICIENCY = 43514
ALPHA1 = 20.79	S1 = 1.0	S2 = -1.0	POINT EFFICIENCY = 43228
ALPHA1 = 20.83	S1 = 1.0	S2 = -1.0	POINT EFFICIENCY = 42942
ALPHA1 = 20.87	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 42978
ALPHA1 = 20.91	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 42538
ALPHA1 = 20.94	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 42100
ALPHA1 = 20.98	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 41664
ALPHA1 = 21.02	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 41229
ALPHA1 = 21.06	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 40796
ALPHA1 = 21.10	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 40365
ALPHA1 = 21.14	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 39934
ALPHA1 = 21.17	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 39502
ALPHA1 = 21.21	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 39070
ALPHA1 = 21.25	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 38638
ALPHA1 = 21.29	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 38206
ALPHA1 = 21.33	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 37774
ALPHA1 = 21.36	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 37342
ALPHA1 = 21.40	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 36910
ALPHA1 = 21.44	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 36478
ALPHA1 = 21.48	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 36046
ALPHA1 = 21.52	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 35614
ALPHA1 = 21.55	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 35182
ALPHA1 = 21.59	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 34750
ALPHA1 = 21.63	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 34318
ALPHA1 = 21.67	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 33886
ALPHA1 = 21.71	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 33454
ALPHA1 = 21.75	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 33022
ALPHA1 = 21.78	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 32590
ALPHA1 = 21.82	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 32158
ALPHA1 = 21.86	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 31726
ALPHA1 = 21.90	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 31294
ALPHA1 = 21.94	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 30862
ALPHA1 = 21.97	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 30430
ALPHA1 = 22.01	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 30000
ALPHA1 = 22.05	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 29570
ALPHA1 = 22.09	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 29140
ALPHA1 = 22.13	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 28710
ALPHA1 = 22.16	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 28280
ALPHA1 = 22.20	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 27850
ALPHA1 = 22.24	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 27420
ALPHA1 = 22.28	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 26990
ALPHA1 = 22.32	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 26560
ALPHA1 = 22.36	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 26130
ALPHA1 = 22.39	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 25700
ALPHA1 = 22.43	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 25270
ALPHA1 = 22.47	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 24840
ALPHA1 = 22.51	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 24410
ALPHA1 = 22.55	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 23980
ALPHA1 = 22.58	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 23550
ALPHA1 = 22.62	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 23120
ALPHA1 = 22.66	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 22690
ALPHA1 = 22.70	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 22260
ALPHA1 = 22.74	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 21830
ALPHA1 = 22.77	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 21400
ALPHA1 = 22.81	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 20970
ALPHA1 = 22.85	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 20540
ALPHA1 = 22.89	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 20110
ALPHA1 = 22.93	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 19680
ALPHA1 = 22.96	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 19250
ALPHA1 = 23.00	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = 18820

Computer program INVOLA (cont)

ALPHA1 = 23.04	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = .37332
ALPHA1 = 23.08	S1 = -1.0	S2 = -1.0	POINT EFFICIENCY = .36928
ALPHA1 = 23.12	S1 = -1.0	S2 = 1.0	POINT EFFICIENCY = .35055
ALPHA1 = 23.16	S1 = -1.0	S2 = 1.0	POINT EFFICIENCY = .35378
ALPHA1 = 23.19	S1 = -1.0	S2 = 1.0	POINT EFFICIENCY = .35700
ALPHA1 = 23.23	S1 = -1.0	S2 = 1.0	POINT EFFICIENCY = .36021
ALPHA1 = 23.27	S1 = -1.0	S2 = 1.0	POINT EFFICIENCY = .36342
ALPHA1 = 23.31	S1 = -1.0	S2 = 1.0	POINT EFFICIENCY = .36663
ALPHA1 = 23.35	S1 = -1.0	S2 = 1.0	POINT EFFICIENCY = .36983
ALPHA1 = 23.38	S1 = -1.0	S2 = 1.0	POINT EFFICIENCY = .37303
ALPHA1 = 23.42	S1 = -1.0	S2 = 1.0	POINT EFFICIENCY = .37623
ALPHA1 = 23.46	S1 = -1.0	S2 = 1.0	POINT EFFICIENCY = .37942
ALPHA1 = 23.50	S1 = -1.0	S2 = 1.0	POINT EFFICIENCY = .38261
ALPHA1 = 23.54	S1 = -1.0	S2 = 1.0	POINT EFFICIENCY = .38579
ALPHA1 = 23.57	S1 = -1.0	S2 = 1.0	POINT EFFICIENCY = .38897
ALPHA1 = 23.61	S1 = -1.0	S2 = 1.0	POINT EFFICIENCY = .39214
ALPHA1 = 23.65	S1 = -1.0	S2 = 1.0	POINT EFFICIENCY = .39531

CYCLE EFFICIENCY = .385

REFERENCE

- B-1 G.G. Lowen, City College of N.Y., and F.R. Tepper, ARRADCOM, "Fuze Gear Train Analysis," Technical Report ARLCD-TR-79030, ARRADCOM, Dover, NJ, December 1979.

APPENDIX C

DESIGN OF CLOCK TOOTH GEAR AND PINION SET
ACCORDING TO BRITISH STANDARD NO. 978

The present appendix deals with the design of clock teeth according to British Standard No. 978 (ref C-1): Gears for Instruments and Clockwork Mechanisms; Part 2, Cycloidal Type Gears.*

Computer program BRITSTD, shows the design of gear and pinion meshes with clock teeth in such a manner that its output data may serve as the input data for the computer programs CLOCK1, CLOCK2, CLOCK3, and CLOCK4 of Fuze Gear Train Analysis (ref C-2).

British Standard No. 978

The British Standard No. 978 (ref C-1) is used to determine the important dimensions for clock type gears and pinions. It originally employs the module (m) as a basic parameter. It is presently more practical to operate in terms of diametral pitch (P_d), so that

$$P_d = \frac{1}{m} \quad (C-1)$$

With the above, the module may become an irrational fraction.

Gear Design Parameters

The important design parameters for the gears of step-up meshes are shown in tables 2 and 3 of reference C-1. These parameters are: the tooth thickness along the pitch circle, the addendum, and the radius of curvature of the addendum. The addendum factor f as well as the addendum radius factor f_r of table 3 of reference C-1 are functions of the gear ratio and the number of teeth in the mating pinion. Similar information is given by charts 1 and 2 of reference C-1.

Pinion Design Parameters

Pinions are designed according to clause 5, and figures 3 and 4, as well as table 4 of reference C-1.

*This standard was used since it was the only complete standard available to the authors at the time this work was undertaken.

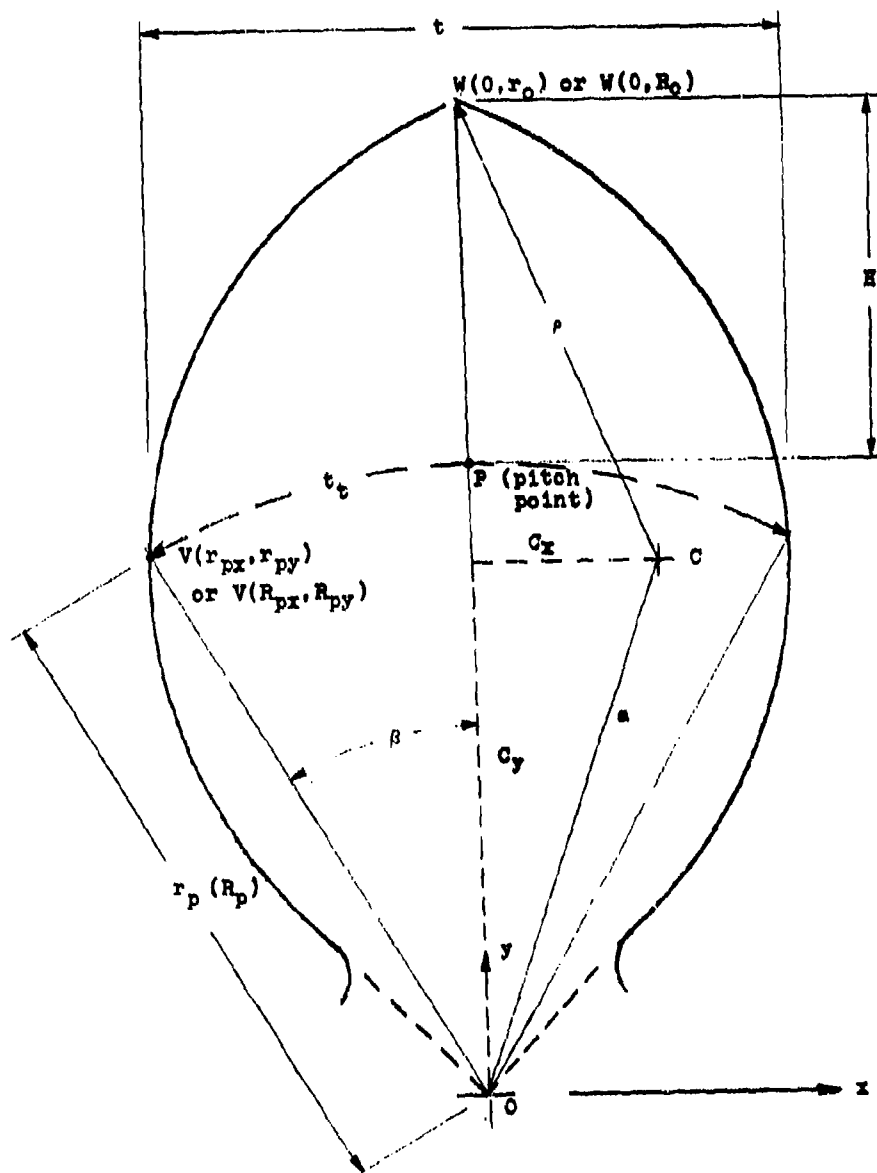


Figure C-1. Geometry of clock tooth for determination of center of curvature C

Clock Tooth Design With British Standard

1. Determination of Center of Curvature of Addendum Radius

Before the clock gear design program proper can be shown, it is necessary to derive a procedure by which the location of the center of curvature C of the addendum radius of curvature may be determined whenever the center of curvature is not located on the intersection of the center line of the tooth and the pitch circle, i.e., the addendum height equals the radius of curvature of the addendum.

The British Standard (ref C-1) provides information concerning the tooth thickness t_t along the pitch circle, the addendum height H , as well as the radius of curvature ρ of the addendum. (Note change of nomenclature when compared to reference C-1.)

A schematic representation of a clock tooth which is used in the determination of the coordinates C_x and C_y of the center of curvature C is shown in figure C-1. The following derivation is based on the idea that the location of the center of curvature of a circle of radius ρ may be determined if the coordinates of the two points W and V on this circle are known. The equation of this circle is given by

$$(x - C_x)^2 + (y - C_y)^2 = \rho^2 \quad (C-2)$$

For point V with the known coordinates $x = r_{px}$ and $y = r_{py}$, the above becomes

$$(r_{px} - C_x)^2 + (r_{py} - C_y)^2 = \rho^2 \quad (C-3)$$

For point W with the known coordinates $x = 0$ and $y = r_o$, one obtains

$$C_x^2 + (r_o - C_y)^2 = \rho^2 \quad (C-4)$$

where

$$r_p = \text{pitch radius}$$

$$r_o = r_p + H \quad (C-5)$$

$$\beta = \tan^{-1}(t_t/2r_p) \quad (C-6)$$

$$r_{px} = -r_p \sin\beta \quad (C-7)$$

$$r_{py} = r_p \cos\beta \quad (C-8)$$

Simultaneous solution of equations C-3 and C-4 leads to

$$C_y = \frac{-(CD - r_o E^2) \pm \sqrt{(CD - r_o E^2)^2 - (D^2 + E^2)(C^2 - AE^2)}}{D^2 + E^2} \quad (C-9)$$

and

$$C_x = \frac{C + DC_y}{E} \quad (C-10)$$

where, in the above

$$A = \rho^2 - r_o^2 \quad (C-11)$$

$$B = \rho^2 - r_p^2 \quad (C-12)$$

$$C = A - B \quad (C-13)$$

$$D = 2(r_o - r_{py}) \quad (C-14)$$

$$E = 2r_{px} \quad (C-15)$$

It is to be noted that the smaller of the two possible solutions in equation C-9 must govern.

2. Computer Program BRITSTD

The computer program BRITSTD is designed to furnish the input parameters necessary for computer programs CLOCK1, CLOCK2, CLOCK3, and CLOCK4 of reference C-2.

Input Parameters. The following parameters represent the input data for the computer program:

- PSUBD = P_d , the diametral pitch.
- NG = N_G , number of teeth of the gear
- NP = N_p , number of teeth of the pinion

- F = f , constant for addendum computation (tables 2 and 3 or chart 1 of reference C-1). Obtained by linear interpolation if not directly available from standard.
- FR = f_r , constant for determination of radius of curvature P (see tables 2 and 3 or chart 2, ref C-1). Also obtained by linear interpolation if not directly available from tables.
- PROFILE = 1, corresponds to Profile A of figure 4 and table 4 (ref C-1)
- PROFILE = 2, corresponds to Profile B of figure 4 and table 4 (ref C-1)
- PROFILE = 3, corresponds to Profile C of figure 4 and table 4 (ref C-1)
- ISTOP = arbitrary single digit integer for multiple data sets. Must be zero for last data set.

Computations.

Design of Gear. To start with, the program determines the module with the help of equation C-1. It further determines (for nomenclature, see figure C-1):

TTG = t_{tG} , according to table 2 of reference C-1. Note that the subscript G stands for gear.

ADDG = H_G , according to table 2 of reference C-1

RHOG = ρ_G , according to table 2 of reference C-1

CAPRP = $R_p = \frac{N_G m}{2}$

ROG = $R_{OG} = R_p + H_G$

BETAG = $\beta_G = \frac{t_{tG}}{(2R_p)}$

CAPRPX = R_{px} , the x coordinate of point V (fig. C-1)

CAPRPY = R_{py} , the y coordinate of point V (fig. C-1)

The subroutine CENTER computes the x and y coordinates C_x and C_y of the center of curvature according to equations C-10 and C-9, respectively, together with the distance $a = OC$, as well as the maximum tooth thickness according to

$$t = 2 (p - C_x) \quad (C-16)$$

For programming purposes the maximum tooth thickness of the gear becomes

$$TG = t_G$$

while for the pinion it is expressed by

$$TP = t_p$$

Pinion Design. The computation of the pinion parameters starts with the determination of the pinion radius

$$RP = r_p$$

It is to be noted that the designations of all pinion variables are similar to those of the gear variables with the letter P substituted for the letter G.

Statement numbers 29 through 34 represent profile selection tests according to figure 4 and table 4 of reference C-1. The resulting computations depend upon the pinion profile chosen as well as the number of pinion teeth involved. The specific pinion parameters are computed according to the formulae in the table 4 (ref C-1). Whenever the addendum radius center of curvature does not coincide with the pitch point, subroutine CENTER is called for the determination of the desired dimensions.

Mesh Starting Test. The mesh starting test is based upon equation E-49 (ref C-2), which, when satisfied, assures that initial contact is made in the round on round phase of contact. To perform this test, the parameters b (the center distance between gear and pinion), the angle γ_G , according to equation D-5 (ref C-2), and the length of flat f_G , according to equation D-7, (ref C-2), must first be determined. If the mesh starts in the normal manner, the program will print out MESH BEGINS IN NORMAL MANNER. In case the mesh causes an abnormal situation, the program will print MESH BEGINS WITH FLAT ON ROUND.

Output. The output of the program is best explained with the help of the first of the five sets of results shown at the end of the program. The underlined values represent the needed inputs to all computer programs dealing with clock teeth. The relevant values of the first three sets of results will serve as input to the revised computer program CLOCK3, as given in appendix D. Similarly, the relevant values of the fourth and fifth sets of results represent input for the revised computer program CLOCK4, given in appendix E.

Input Parameters.

PSUBD = P_d = 44
F = f = 1.450
FR = f_r = 2.137
PROFILE = 2.0
NG = n_G = 42
NP = n_p = 8

Computed Values.

For the gear

CAPRP = R_p = 0.47727 in.
(1.2122 cm)
AG = a_G = 0.47343 in.
(1.2025 cm)
RHOG = ρ_G = 0.04857 in.
(0.1234 cm)
TG = t_G = 0.03609 in.
(0.0917 cm)
TTG = t_{tG} = 0.03568 in.
(0.0906 cm)
CXG = c_{xG} = 0.03052 in.
(0.0775 cm)
CYG = c_{yG} = 0.47245 in.
(1.2000 cm)

For the pinion

RP = r_p = 0.09091 in.
(0.2309 cm)
AP = a_p = 0.09083 in.
(0.2307 cm)
RHOP = ρ_p = 0.01591 in.
(0.0404 cm)
TP = t_p = 0.02382 in.
(0.0605 cm)
TTP = t_{tp} = 0.02386 in.
(0.0606 cm)
CXP = c_{xp} = 0.00400 in.
(0.0102 cm)
CYP = c_{yp} = 0.09074 in.
(0.2305 cm)

Also, MESH BEGINS IN NORMAL MANNER

Computer program BRITSTD

PROGRAM BRITSTD 74/7A 021-1 ETM 4.0-428 01/12/79 13:58.07 PAGE 1 C

```

1      PROGRAM BRITSTD (INPUT, OUTPUT, TAPES=INPUT, TAPES=OUTPUT)
      REAL NG, NP, NQD
      1000 READ (5,1) PSUMD, NG, NC, F, FR, PROFILE, ISTOP
      1 FORMAT (I5, 2, S, 0, I, 1)
      5      WRITE (6,2) PSUMD, FR, PROFILE
      2 FORMAT (I5, 2, S, 0, I, 1, /, 1X, 'OF', 1X, I5, 2, S, 0, I, 1, /, 1X, 'SER', 1X, I5, 2, S, 0, I, 1)
      1010 PROFILE = F*3.0/7
      NQD = 1./PSUMD

      C      DESIGN OF REAR
      C
      14      TTG = 1.57080D
      ADDG = F*MQD
      RMQD = FR*MQD
      15      CAPRP = NG*MQD/2.
      NQD = CAPRP * ADDG
      DETAG = TTG/2. * CAPRP
      CAPRPY = CAPRP*COS(DETAG)
      20      CALL CENTER (RMQD, NQD, CAPRPY, CAPRPY*2, TTG, CIG, CIG)
      WRITE (6,3) CAPRP, RMQD, TTG, CIG, CIG
      3 FORMAT (I5, 2, S, 0, I, 1, /, 1X, 'SER', 1X, I5, 2, S, 0, I, 1, /, 1X, 'OF', 1X, I5, 2, S, 0, I, 1, /, 1X, 'SER', 1X, I5, 2, S, 0, I, 1)
      1016 NG = F*5/64, NQD = F*5/64, TTG = F*5/64, CIG = F*5/64
      2016 NG = F*5/64, NQD = F*5/64, TTG = F*5/64, CIG = F*5/64

      C      PINION DESIGN
      C
      NP = NG*MQD/2.
      30      IF (NP .LE. 10) .AND. PROFILE .EQ. 1.160 TO 4
      IF (NP .LE. 10) .AND. PROFILE .EQ. 2.160 TO 6
      IF (NP .LE. 10) .AND. PROFILE .EQ. 3.160 TO 7
      IF (NP .GE. 11) .AND. PROFILE .EQ. 1.160 TO 8
      IF (NP .GE. 11) .AND. PROFILE .EQ. 2.160 TO 9
      IF (NP .GE. 11) .AND. PROFILE .EQ. 3.160 TO 10
      35      A, RMQD = 525*MQD
      NP = 2 * RMQD
      40      WRITE (6,5) RMQD, NP, TTG, NP
      5 FORMAT (I5, 2, S, 0, I, 1, /, 1X, 'SER', 1X, I5, 2, S, 0, I, 1, /, 1X, 'OF', 1X, I5, 2, S, 0, I, 1, /, 1X, 'SER', 1X, I5, 2, S, 0, I, 1)
      1016 NG = F*5/64, NQD = F*5/64, TTG = F*5/64, CIG = F*5/64
      60 TO 162
      4      ITP = 1.05*MQD
      ADDP = .07*MQD
      RMQD = .79*MQD
      45      ROP = FP * ADDP
      GETAP = ITP/(2 * ROP)
      RPY = ROP * ITP (GETAP)
      RPY = ROP * COS (GETAP)
      50      CALL CENTER (RMQD, NQD, RPY, RPY*2, ITP, CIP, CIP)
      70 TO 164
      7      ITP = 1.05*MQD
      ADDP = .075*MQD
      RMQD = 1.05*MQD

```

Computer program BRITSTD (cont)

PROGRAM BRITSTD	TA/TA	OPTS1	ETN A.A.428	81/12/78	15.58.47	PAGE 2
55						
60						
65						
70						
75						
80						
85						
90						
95						
100						

Computer program BRITSTD (cont)

```

SUBROUTINE CENTER (X0,Y0,RA,RY,AA,T,CX,CY)
      1
      SUBROUTINE CENTER (X0,Y0,RA,RY,AA,T,CX,CY)
      A = RMO*RMQ - RO*RO
      B = RMQ*RMQ - RY*RY
      C = A - B
      D = 2.* (RO - RY)
      E = 2.*RX
      ROOT = SORT1 (C*D - RO*E*E)*E2 - (D*D*E*E)* (C*(A*E*E))
      CY1 = (- (C*D - RO*E*E) + ROOT) / (D*D*E*E)
      CY2 = (- (C*D - RO*E*E) - ROOT) / (D*D*E*E)
      IF (CY1 - LY - CY2) ISU TO 1
      CY = CY1
      GO TO 2
      1 CY = CY1
      2 CX = (C*CY1)/E
      AX = SORT1 (CX*CX + CY*CY)
      T = 2.* (RMO*CX)
      RETURN
      END

```

Computer program BRITSTD (cont)

PSURN = 44.
F = 1.450
Fe = 2.137
PROFILE = ?.

CAPRP = .47727
 AG = .47343
 RHOG = .04857
 TG = .03609
 NG = 42.
 TTG = .03568
 CxG = .03052
 CYG = .47245

RP = .09091
 AP = .09083
 RHOP = .01591
 TD = .02382
NP = R.
 TTP = .02386
 CXP = .08406
 CYP = .09074

WFSH BEGINS IN NORMAL MANNER

Computer program BRITSTD (cont)

PSUAN = 65.
F = 1.465
FR = 2.160
PROFILE = 2.
CAPRP = .20769
AG = .20559
RHOG = .03323
IG = .02438
NG = 27.
ITG = .02415
CXG = .02104
CYG = .20451
RP = .06923
AP = .06917
RHOP = .01077
TP = .01613
NP = 9.
TTP = .01615
CXP = .00270
CYP = .06911
MFSH BEGINS IN NORMAL MANNER

Computer program BRITSTD (cont)

PSURN = 77.
 F = 1.465
 FP = 2.140
 PROFILE = 2.
 CAPRP = .17532
 AG = .17355
 RHOG = .02805
 TG = .02058
 NG = 27.
 TTG = .02039
 CXG = .01776
 CYG = .17264
 RP = .05844
 AP = .05839
 RHOP = .00909
 TP = .01362
 NP = 9.
 TTP = .01364
 CXP = .00228
 CYP = .05834

MFISH REGINS IN NORMAL MANNER

Computer program BRITSTD (cont)

PSUBD = 50.
 F = 1.467
 FR = 2.161
 PROFILE = 2.
 CAPRP = .55080
 AG = .54656
 RHOG = .04322
 TG = .03175
 NG = 55.
 YTG = .03140
 CKG = .02735
 CYO = .54587
 RP = .08000
 AP = .07993
 RHOP = .01400
 TP = .02096
 NP = 8.
 TTP = .02100
 CXP = .00352
 CYP = .07385

MESH BEGINS IN NORMAL MANNER

Computer program BRITSTD (cont)

PSUBD = 70.
 F = 1.467
 FR = 2.161
 PROFILE = 2.
 CAPRP = .39285
 AG = .39040
 RMOP = .03087
 TG = .02268
 NG = 55.
 TIG = .02243
 CAG = .01953
 CYG = .38991
 RP = .05714
 AP = .05709
 RMOP = .01000
 TP = .01437
 NP = 8.
 TTP = .01500
 CXP = .00251
 CYP = .05704

MESH BEGINS IN NORMAL MANNER

REFERENCE

- C-1 British Standard No. 978 for Gears for Instruments and Clockwork Mechanisms, Part 2, Cycloidal Type Gears (1952).
- C-2 G.G. Lowen, City College of N.Y., and F.R. Tepper, ARRADCOM, "Fuze Gear Train Analysis," Technical Report ARLCD-TR-79030, ARRADCOM, Dover, NJ, December 1979.

APPENDIX D
COMPUTER PROGRAM CLOCK3 (REVISED)

111/112

The original program descriptions were given in appendix I of Fuze Gear Train Analysis (ref D-1). The following appendix contains revised descriptions, listings and sample outputs of computer program CLOCK3, which computes point and cycle efficiencies for three pass clock gear trains in a spin environment.

The following changes were made:

1. The diametral pitches of all three meshes are given as data and are printed in the output.

2. The initialization parameters J are introduced. They are given as part of the data and are listed in the output. These parameters allow the initial points of contact of the three meshes to be chosen at arbitrary points within the ranges of possible contact points.

The kinematics of computer program CLOCK3 is based on the work in appendix G (ref D-1), while the moment input-output relationships are derived in appendix H (ref D-1). Even though the fuze related geometry produces different expressions for the various meshes, the kinematic computations of the individual meshes are very similar to those shown in computer program CLOCK1 in appendix F (ref D-1) for the single mesh in the standard position. It is also assumed that all three meshes will have been tested by computer program CLOCK1 (ref D-1) for their geometric suitability, i.e., whether there is enough room for tip radii.

Input Parameters

The following parameters represent the input data for the program (for explanations and nomenclature, see appendixes C and F, reference D-1):

PSUBD1, PSUBD2, PSUBD3 = P_{d1} , P_{d2} , P_{d3}

MU, coefficient of friction

RPM, spin velocity

CAPRP1, CAPRP2, CAPRP3, RP2, RP3, RP4, pitch radii of gears and pinions with nomenclature of figure G-1 (ref D-1)

RHOG1, RHOG2, RHOG3, RHOP1, RHOP2, RHOP3, radii of curvature of circular arc portion of gear and pinion teeth

$ACG1, ACG2, ACG3^{D-1} = a_{CG1}$, distance from the center of rotation of the gear of the i^{th} mesh to the center of curvature of the circular arc portion of the gear tooth. (Unless otherwise noted, this and all following numbering schemes refer to those associated with the mesh mechanics as given in the text of appendixes G and H of reference D-1).

$ACP1, ACP2, ACP3 = a_{CP1}$, distance from the center of rotation of the pinion of the i^{th} mesh to the center of curvature of the circular arc portion of the pinion tooth

$R1, R2, R3, R4 = R_i$ (nomenclature of fig. G-1, ref D-1)

$TG1, TG2, TG3, TP1, TP2, TP3$, maximum thicknesses of gear and pinion teeth (mesh nomenclature)

$NG1, NG2, NG3, NP2, NP3, NP4$, numbers of teeth in various gears and pinions (nomenclature of fig. G-1, ref D-1)

$RHO1, RHO2, RHO3, RHO4$, gear and/or pinion pivot radii (nomenclature of fig. G-1, ref D-1)

$M1, M2, M3, M4$, masses of gear and/or pinion combinations

$MD = md^2$, see appendix A of this report

K , range divisor

$J1, J2, J3$, initialization parameters

The angular velocity of the input gear is incorporated into the program as $PHDOT1 = 1$. All velocity computations are based on this model. The input motion in the fuze gearing model is negative (fig. G-1, ref D-1).

Computations

Computation of Gear Tooth Parameters

The tooth parameters of the gears and pinions of all three meshes are first computed. These computations are essentially the same as those shown in computer program CLOCK1 (ref D-1) for a single mesh. Certain parameters are omitted because they have been checked separately by using computer program CLOCK1 (ref D-1) and are not required for the kinematics of computer program CLOCK3 (ref D-1).

^{D-1}Since many parts of the computer program were written before the nomenclature for these distances was changed in the report from a_{CG1} and a_{CP1} to a_{C1} and a_{P1} , there is a certain discrepancy between the program and the report.

In addition, the pivot to pivot distances B1, B2 and B3 are obtained.

Computation of MIN, GAMMAS and BETAS

To begin with, the program computes the input moment

$$MIN = M_{in} = md^2 \omega^2 \quad (D-1)$$

Subsequently, the angles $\gamma_2, \gamma_3, \gamma_4$ and $\beta_1, \beta_2, \beta_3$ are established according to the expressions of appendix A (ref D-1).

Computation of Other Parameters

The angles $\Delta\phi$ and $\Delta\psi$, between the centerlines of adjacent gear and pinion teeth, respectively, are determined in this section of the computations. In addition, the lengths L_i are found (equations G-7, G-53 and G-88, ref D-1). Finally, the centrifugal forces Q_1, Q_2, Q_3 and Q_4 are computed according to equations H-65, H-46, H-25 and H-6 (ref D-1), respectively.

Preliminary Computations for Mesh 1

Determination of Transition Angle. The primary consideration for determining the transition angles in the fuze related clock gear meshes is identical with that used in appendix F (ref D-1). The transition angle ψ_T is established as that angle for which, depending upon whether the input angle ϕ has counter-clockwise or clockwise motion, a small increase or decrease in ϕ , respectively, will cause the associated value of g to become smaller than its transition value f_p . Since the gear mesh 1 turns in a clockwise direction, the above increment of ϕ will be negative.

The program uses this criterion in the following manner:

1. Transition angles ψ_{1T1} and ψ_{1T2} are computed according to equation G-39 (ref D-1).
2. The subroutine TRANS1 (which is valid for meshes in which the input gear has clockwise rotation, as is the case also for mesh 3) is called, and the angle ϕ_{1T1} (PHIT), which is associated with ψ_{1T1} , is computed with the help of equations G-40 and G-41 (ref. D-1).
3. The angle ϕ is made slightly smaller than ϕ_{1T1} to produce the angle PHINEXT, and equation G-29 (ref D-1) is used to find the associated angle PSINEX. Since there are two such angles, the subroutine selects the one which is

closest in value to the transition angle ψ_{1T1} . Subsequently, the associated value of g_{11} is computed according to equation G-27 (ref D-1).

4. Steps 1 and 2 are then repeated identically for the second transition angle ψ_{1T2} . This results in the determination of g_{12} .

5. Control returns to the main program, and that value of ψ_{1T} is chosen for which the associated value of g_1 is smaller than f_{p1} .

For checking, a subsidiary test, which is similar to the one shown in appendix F (ref D-1), is added to the program. It is based on the idea that, for the correct transition angle ψ_{1T} , the line representing the flat portion of the pinion will make a smaller angle with the centerline O_1O_2 than will be the case for the incorrect one. TEST11 and TEST12 find these angles with the help of the expressions shown below. These expressions hold for all values of β_1 and make use of a new variable ψ_{test} , which had to be introduced since the tests require that the transition angles be expressed in a range between -180° and $+180^\circ$. Thus,

For $0^\circ < \psi_{test} < 180^\circ$

$$TEST11 = \left| \pi - \beta_1 + \psi_{test} - \alpha_{p1} \right| \quad (D-2)$$

For $-180^\circ < \psi_{test} < 0^\circ$

$$TEST12 = \left| \pi + \beta_1 - (\psi_{test} + 2\pi - \alpha_{p1}) \right| \quad (D-3)$$

To determine the angle ψ_{test} , let

$$\psi_{test} = \psi_{1T} \text{ if } -180^\circ < \psi_{1T} < 180^\circ \quad (D-4)$$

$$\psi_{test} = \psi_{1T} + 2\pi \text{ if } \psi_{1T} < -180^\circ \quad (D-5)$$

$$\psi_{test} = \psi_{1T} - 2\pi \text{ if } \psi_{1T} > 180^\circ \quad (D-6)$$

Determination of Correct Sign for Round on Flat Regime. The sign preceding the square root in equation G-29 (ref D-1), for the round on flat regime, is determined with the help of ϕ_{1T} . The condition yielding that angle ψ_{1T} which is closest to the angle ψ_{1T} governs. The variable SIGN1F is used for the sign in question.

Computation of Latest and Earliest Possible Values of ϕ_1 and ψ_1 . The latest and earliest possible values of the gear and pinion angles ϕ_1 and ψ_1 , respectively, are found by continuously evaluating the round on flat regime equation G-29 (ref D-1), using the previously determined value of SIGNIF, and simultaneously checking the contact condition for the subsequent set of teeth as given by equation G-46 (ref D-1).^{D-2} This loop is initiated at the transition angle ϕ_{1T} , and it is terminated when the condition of equation G-46 (ref D-1) is met. This allows the determination of the angles PH1F and PS1FF, at which the first set of teeth loses contact, as well as of the angles PH1I and PS1I at which the second set of teeth simultaneously comes into engagement. The earliest possible engagement angles PH1I and PS1I are obtained by adding $\Delta\phi_1$ to the loss of contact angle PH1F and by subtracting $\Delta\psi_1$ from the loss of contact angle PS1FF. (PH1F and PS1FF represent the latest possible values of ϕ_1 and ψ_1 .)

Determination of Correct Sign for Round on Round Regime. Equation G-12 (ref D-1) is used to determine the angle ψ_1 , while the gear and pinion are in the round on round regime. The correct sign for this expression is obtained by comparing the value ψ_1 , as computed with PH1I, with the value for PS1I. SIGNR is the variable used for the desired sign.

Preliminary Computations for Mesh 2

Determination of Transition Angle. The primary criterion for determining the transition angle is again similar to that used in appendix F (ref D-1) and described earlier for mesh 1.

1. Transition angles ψ_{2T1} and ψ_{2T2} are computed according to equation G-79 (ref D-1).

2. The subroutine TRANS2, which is valid for meshes in which the input gear has counterclockwise rotation, is called, and the angle ϕ_{2T1} , which is associated with ψ_{2T1} is computed with the help of equations G-80 and G-81 (ref D-1).

3. The angle ϕ_2 is made slightly larger than ϕ_{2T1} to produce the angle PHINEXT, and equation G-71 (ref D-1) is used to find the associated output angle PSINEX. Since there are two such angles, the subroutine selects the one which is closest to the transition value ψ_{2T1} . Subsequently, the associated value of δ_{21} is computed according to equation G-69 (ref D-1).

^{D-2}As in appendixes A and B, the actual initial contact does not necessarily coincide with the earliest possible one. Again, use is made of the initialization parameters J_1 ($i = 1, 2, 3$).

4. Steps 2 and 3 are then repeated identically for the second transition angle ψ_{2T2} . This results in the determination of g_{22} .

5. Control returns to the main program, and that value of ψ_{2T} is chosen for which the associated value of g_2 is smaller than f_{p2} .

The procedure for the associated subsidiary test for the transition angle is similar to that for mesh 1 and is given by:

For $0^\circ < \psi_{test} < 180^\circ$

$$TEST21 = \left| \pi - \beta_2 + \psi_{test} + \alpha_{p2} \right| \quad (D-7)$$

For $-180^\circ < \psi_{test} < 0^\circ$

$$TEST22 = \left| \beta_2 + \pi - (\psi_{test} + 2\pi + \alpha_{p2}) \right| \quad (D-8)$$

To determine the angle ψ_{test} , let

$$\psi_{test} = \psi_{2T} \text{ if } -180^\circ < \psi_{2T} < 180^\circ \quad (D-9)$$

$$\psi_{test} = \psi_{2T} + 2\pi \text{ if } \psi_{2T} < -180^\circ \quad (D-10)$$

$$\psi_{test} = \psi_{2T} - 2\pi \text{ if } \psi_{2T} > 180^\circ \quad (D-11)$$

Determination of Correct Sign for Round on Flat Regime. The sign preceding the square root in equation G-71 (ref D-1), for the round on flat regime, is determined with the help of ϕ_{2T} . The condition yielding that angle ψ_{2T} which is closest to the angle ψ_{2T} governs. The variable SIGN2F is used for the sign in question.

Computation of Latest and Earliest Possible Values of ϕ_2 and ψ_2 . The latest and earliest possible values of the gear and pinion angles ϕ_2 and ψ_2 , respectively, are found by continuously evaluating the round on flat equation G-71 (ref D-1), using the previously determined value of SIGN2F, and simultaneously checking the contact condition for the subsequent set of teeth, as given by equation G-86 (ref D-1). This loop is initiated at the transition angle ϕ_{2T} and is terminated when the condition of equation G-86 (ref D-1) is met. (Recall that in meshes 1 and 3 the driving gear turns clockwise, while in mesh 2 it turns in a counterclockwise direction.) This allows the determination of the two angles PHI2F and PSI2FF at which the first set of teeth loses contact as well as of the angles PHI2I and PSI2I at which the second set of teeth simultaneously comes into contact. The earliest possible engagement angles PHI2I and PSI2I are obtained by

subtracting $\Delta\phi_2$ from the loss of contact angle PSI2F and by adding $\Delta\psi_2$ to the loss of contact angle PSI2FF . (PHI2F and PSI2FF represent the latest possible values of ϕ_2 and ψ_2 .)

Determination of Correct Sign for Round on Round Regime. Equation G-58 (ref D-1) is used to determine the angle ψ_2 while the gear and pinion are in the round on round phase of motion. The correct sign for this expression is obtained by comparing the value of ψ_2 , as computed with PHI2I , with the previously obtained value for PSI2I . SIGN2R is the variable used for the desired sign.

Preliminary Computations for Mesh 3

Determination of Transition Angle. The determination of the transition angle for mesh 3 runs along parallel lines to the one shown for mesh 1 since the driving gear also rotates in a clockwise direction. In all cases, the parameters of appendix G (ref D-1) are used.

1. Transition angles ψ_{3T1} and ψ_{3T2} are computed with the help of equation G-99 (ref D-1).

2. The subroutine TRANS1 determines the angle ϕ_{3T1} , associated with ψ_{3T1} , to equations G-100 and G-101 (ref D-1).

3. PHINEXT , which is now obtained by a decrease of the angle ϕ_3 from ϕ_{3T1} , serves as the input variable of equation G-94 (ref D-1), and is used to determine PSINEX . Appropriate controls, as described before, determine the angle ψ_{3T1} . In addition, the associated value of g_{31} is computed with the help of equation G-95 (ref D-1).

4. Steps 2 and 3 are again repeated for the second transition angle ψ_{3T2} and g_{22} is determined.

5. After control is returned to the main program, that value of ψ_{3T} is chosen for which the associated value of g_3 is smaller than f_{p3} .

The subsidiary test for the transition angles runs parallel to that described for mesh 1, i.e.,

For $0^\circ < \psi_{\text{test}} < 180^\circ$

$$\text{TEST31} = \left| \pi - \beta_3 + \psi_{\text{test}} - \alpha_{p3} \right| \quad (\text{D-12})$$

For $-180^\circ < \psi_{\text{test}} < 0^\circ$

$$\text{TEST32} = \left| \pi + \beta_3 - (\psi_{\text{test}} + 2\pi - \alpha_{p3}) \right| \quad (\text{D-13})$$

To determine the angle ψ_{test} , let

$$\psi_{\text{test}} = \psi_{3T} \text{ if } -180^\circ < \psi_{3T} < 180^\circ \quad (\text{D-14})$$

$$\psi_{\text{test}} = \psi_{3T} + 2\pi \text{ if } \psi_{3T} < -180^\circ \quad (\text{D-15})$$

$$\psi_{\text{test}} = \psi_{3T} - 2\pi \text{ if } \psi_{3T} > 180^\circ \quad (\text{D-16})$$

Determination of Correct Sign for Round on Flat Regime. The sign preceding the square root in equation G-94 (ref D-1), for the round on flat regime, is determined with the help of the angle ϕ_{3T} . The condition yielding that angle ψ_{3F} which is closest to the angle ψ_{3T} will govern. The variable SIGN3F is used for the sign in question.

Computation of Latest and Earliest Possible Values of ϕ_3 and ψ_3 . The latest and earliest possible values of the gear and pinion angles ϕ_3 and ψ_3 , respectively, are found by continuously evaluating the round on flat regime equation G-94 (ref D-1), using the previously determined value of SIGN3F, and simultaneously checking the contact condition for the subsequent set of teeth, as given by equation G-102 (ref D-1). This loop is initiated at the transition angle ϕ_{3T} and it is terminated when the condition of equation G-102 (ref D-1) is met. This allows the determination of the two angles PHI3F and PSI3FF at which the first set of teeth loses contact as well as the angles PHI3I and PSI3I at which the second set of teeth simultaneously comes into contact. The earliest possible engagement angles PHI3I and PSI3I are obtained by adding $\Delta\phi_3$ to the loss of contact angle PHI3F and by subtracting $\Delta\psi_3$ from the loss of contact angle PSI3FF. (PHI3F and PSI3FF represent the latest possible values of ϕ_3 and ψ_3 .)

Determination of Correct Sign for Round on Round Regime. Equation G-87 (ref D-1) is used to determine the angle ψ_3 while the gear and pinion are in the round on round phase of motion. The correct sign for this expression is obtained by comparing the value of ψ_3 , as computed with PHI3I, with the previously obtained value for PSI3I. SIGN3R is the variable used for the desired sign.

Gear Train Motion Model: Initial Contact Angles, Point and Cycle Efficiency. The simulation of the gear train model, which is necessary for the computation of both POINTEF and CYCLEFF, is found in a loop, starting with statement label no. 29 (card no. 459) and ending with card no. 824. The motions of the individual driving gears are initialized at the angles PHI1, PHI2 and PHI3, respectively, with the help of the initialization parameters J_1 according to

$$\phi_i = \phi_{1I} + J_1 (\phi_{1F} - \phi_{1I}) \quad (i=1,2,3) \quad (\text{D-17})$$

The additional parameter J_4 is set equal to zero to mark the first cycle of computations (see statement no. 456). J_4 becomes equal to unity for all subsequent computations (see statement no. 823).

The parameter J_5 is used to distinguish between the two possible contact conditions of mesh no. 1. $J_5 = 0$ whenever the first set of teeth is in contact. $J_5 = 1$ once the latest possible value of ϕ_1 has been reached, and contact must be transferred to the second set of teeth in order to obtain a complete cycle of motion for this mesh. $J_5 = 0$ at all times if $J_1 = 0$, i.e., contact is made in mesh no. 1 at the earliest possible point.

The meshes will be in round on round contact until they reach their respective transition angles PHI1T , PHI2T and PHI3T . Once the transition angles are passed, the meshes will be in round on flat contact. These regimes continue until the latest possible angles PHI1F , PHI2F and PHI3F are reached.

The increment DDPHI1 of the angle PHI1 of the input gear 1 is obtained from an adaptation of equations A-211 and A-213 (ref D-1), in which tooth numbers, rather than base circle radii, are used. The increment DDPHI2 of gear 2 is related to the increment of the pinion angle PSI1 . Similarly, the increment DDPHI3 is obtained with the help of the pinion angle PSI2 .

While the motion of gear 1 is terminated when the angle PHI1 reaches one increment before its starting angle, both gears 2 and 3 must be reset to their respective earliest angles whenever they have reached PHI2F and PHI3F , respectively. ^{D-3}

The appropriate choice of moment equation depends upon which of the eight possible combinations of contact conditions, as indicated by table H-1 (ref D-1), is applicable.

The following discusses the kinematics of the individual meshes as well as the determination of the point and cycle efficiencies in greater detail.

Kinematics.

1. Mesh 1

Depending on whether PHI1 is larger or smaller than PHI1T , the parameters of the round on round or the round on flat regime are computed. (Recall that gear 1 turns in a clockwise direction.)

^{D-3}If $J_1 = 0$, the computation is terminated for $\text{PHI1} < \text{PHI1F} + \text{DDPHI1}$. If $J_1 > 0$, and, therefore, $J_5 = 1$, computation is terminated when $\text{PHI1} < \text{PHI1A} + \text{DDPHI1}$. In the above, PHI1A represents the starting angle of mesh 1 in the manner of equation D-17. (See statement no. 454.)

For the round on round phase, the following calculations are made:

ψ_1 , according to equation G-11 (ref D-1), and with the help of the previously determined SIGN1R

λ_1 , according to equation G-13 and G-14 (ref D-1)

$\dot{\psi}_1$, according to equation G-15 (ref D-1)

$V_{S1/T1R}$, according to equation G-20 (ref D-1)

s_{1R} , according to equation H-1 (ref D-1) as adapted to mesh 1

For the round on flat phase, the following calculations are made:

ψ_1 , according to equation G-29 (ref D-1) and with the help of the previously determined SIGN1F

g_1 , according to equation G-27 (ref D-1)

$\dot{\psi}_1$, according to equation G-30 (ref D-1)

$V_{S1/T1F}$, according to equation G-33 (ref D-1)

s_{1F} , according to equation H-2 (ref D-1) as adapted to mesh 1

2. Mesh 2

The increment DDPHI2, for each round of computations, is obtained with the help of the change in the angle ψ_1 between the present and the previous computation, i.e., as shown at statement label no. 31:

$$DDPHI2 = PSI1 - PSI1P \quad (D-18)$$

For the first round of computations, the previous ψ_1 , i.e., PSI1P, is equal to that PSI1 which corresponds to PHI1A.

It must be recalled that gear 2 rotates in a positive direction, and therefore, the angle ϕ_2 increases with continued motion. The angle PHI2 is re-indexed to PHI2I once it becomes larger than PHI2F.

As for mesh 1, comparison with the transition angle decides whether the mesh is in the round on round or in the round on flat regime.

The following round on round parameters are calculated:

ψ_2 , according to equation G-58 (ref D-1), and with the help of the previously determined SIGN2R

λ_2 , according to equations G-59 and G-60 (ref D-1)

Note that the input angular velocity for mesh 2, i.e., $\dot{\phi}_2$, equals the momentary value of $\dot{\psi}_1$.

$\dot{\psi}_2$, according to equation G-61 (ref D-1)

$V_{S2/T2R}$, according to equation G-63 (ref D-1)

s_{2R} , according to equation H-1 (ref D-1), as adapted to mesh 2

For the round on flat phase, the following calculations are made:

ψ_2 , according to equation G-71 (ref D-1), and with the help of the previously determined SIGN2F

s_2 , according to equation G-69 (ref D-1)

Again, $\dot{\phi}_2$ equals the momentary value of $\dot{\psi}_1$

$\dot{\psi}_2$, according to equation G-72 (ref D-1)

$V_{S2/T2F}$, according to equation G-74 (ref D-1)

s_{2F} , according to equation H-2 (ref D-1), as adapted to mesh 2

3. Mesh 3

The increment DDPHI3, for each round of computations, is obtained with the help of the change in the angle ψ_2 between the present and the previous computation, i.e., as shown at statement label no. 33:

$$DDPHI3 = PSI2 - PSI2P \quad (D-19)$$

For the first round of computations, the previous ψ_2 , i.e., PSI2P, is equal to that PSI2 which corresponds to the initial value of PHI2, as obtained with the help of J_2 .

Gear 3 rotates in a negative (clockwise) direction, and therefore, the angle ϕ_3 decreases with continued rotation. The angle PHI3, which represents this angle, is re-indexed to PHI3I once it becomes smaller than PHI3F.

As for meshes 1 and 2, comparison with the applicable transition angle decides whether the mesh is in the round on round or in the round on flat regime.

The following round on round parameters are calculated:

ψ_3 , according to equation G-87 (ref D-1), and with the help of the previously determined SIGN3R

λ_3 , according to equation G-89 and G-90 (ref D-1)

Note that the input angular velocity for mesh 3, i.e., $\dot{\phi}_3$, equals the momentary value of $\dot{\psi}_2$.

$\dot{\psi}_3$, according to equation G-91 (ref D-1)

$V_{S3/T3R}$, according to equation G-92 (ref D-1)

s_{3R} , according to equation H-1 (ref D-1) as adapted to mesh 3

For the round on flat phase, the following calculations are made:

ψ_3 , according to equation G-94 (ref D-1), and with the help of the previously determined SIGN3F

s_3 , according to equation G-95 (ref D-1)

Again, $\dot{\phi}_3$ is equal to the momentary value of $\dot{\psi}_2$.

$\dot{\psi}_3$, according to equation G-96 (ref D-1)

$V_{S3/T3F}$, according to equation G-97 (ref D-1)

s_{3F} , according to equation H-2 (ref D-1) as adapted to mesh 3

Moment Computations, Point and Cycle Efficiencies. Regardless of the combination of contact conditions, the point efficiency is computed according to equation 3 (ref D-1), i.e.,

$$\epsilon_P = \text{POINTEF} = K_{\text{RATIO}} \frac{M_{O41}}{M_{1n}} \quad (\text{D-20})$$

where, with $\dot{\phi}_1 = -1$,

$$K_{\text{RATIO}} = \left| \dot{\psi}_3 \right| \quad (\text{D-21})$$

The cycle efficiency determination is based on equation C-10 (ref D-1), which represents an adaptation of equation 4 (ref D-1):

$$\epsilon_C = \frac{\Delta\phi_1 \Sigma \epsilon_P}{\phi_{1FIN} - \phi_{1IN}} \quad (D-22)$$

The associated expression in the program, at statement label no. 45, becomes

$$CYCLEFF = -MTOT * DDPHI1 / (PHI1F - PHI1I) \quad (D-23)$$

where

$$MTOT = MTOT + POINTEF \quad (D-24)$$

The moment computations begin with the statement label no. 35, and initially consist of the determination of the variables A1 to A64 and C1 to C32, appendix H (ref D-1). The governing contact combination (table H-1, ref D-1) is determined with the help of the 8 moment control statements, which start with card no. 748. Once the appropriate combination is established, the program is directed to one of the 8 associated moment expressions. These expressions for M_{04} coincide in nomenclature with those given by equations H-81, H-118, H-158, H-180, H-216, H-218, H-239 and H-241 (ref D-1). They are listed in the above order, beginning with statement label no. 36 and ending with statement label no. 43.

In devising the control statements, the manner of rotation of the individual mesh input gears had to be taken into account. Thus:

For mesh 3:

Round on round (R) corresponds to $PHI3I > PHI3 > PHI3T$

Round on flat (F) corresponds to $PHI3T > PHI3 > PHI3F$

For mesh 2:

Round on round (R) corresponds to $PHI2I < PHI2 < PHI2T$

Round on flat (F) corresponds to $PHI2T < PHI2 < PHI2F$

For mesh 1:

Round on round (R) corresponds to $\text{PHI1I} > \text{PHI1} > \text{PHI1T}$

Round on flat (F) corresponds to $\text{PHI1T} > \text{PHI1} > \text{PHI1F}$

Output

The output of the program is best explained with the help of the sample problem at the end of the program.

Input Parameters (first sets of gear data, appendix C)

Mesh 1

CAPRP1	=	R_{p1}	=	0.47727 in. (1.2122 cm)	PSUBD1	=	P_{d1}	=	44
RP2	=	r_{p2}	=	0.09091 in. (0.2309 cm)	J1	=	0.90		
ACG1	=	a_{G1}	=	0.47343 in. (1.2025 cm)					
ACP1	=	a_{p1}	=	0.09083 in. (0.2307 cm)					
RHOG1	=	ρ_{G1}	=	0.04857 in. (0.1234 cm)					
RHOP1	=	ρ_{p1}	=	0.01591 in. (0.0404 cm)					
TG1	=	t_{G1}	=	0.03609 in. (0.0917 cm)					
TP1	=	t_{p1}	=	0.02382 in. (0.0605 cm)					
NG1	=	n_{G1}	=	42					
NP2	=	n_{p2}	=	8					

Mesh 2

CAPRP2	=	R_{p2}	=	0.20769 in. (0.5275 cm)	PSUBD2	=	P_{d2}	=	65
RP3	=	r_{p3}	=	0.06923 in. (0.1758 cm)	J2	=	0.90		
ACG2	=	a_{G2}	=	0.20559 in. (0.5222 cm)					
ACP2	=	a_{p2}	=	0.06917 in. (0.1757 cm)					

RHOG2 = ρ_{G2} = 0.03323 in. (0.0844 cm)
 RHOP2 = ρ_{P2} = 0.01077 in. (0.274 cm)
 TG2 = t_{G2} = 0.02438 in. (0.0619 cm)
 TP2 = t_{P2} = 0.01613 in. (0.0410 cm)
 NG2 = n_{G2} = 27
 NP3 = n_{P3} = 9

Mesh 3

CAPRP3 = R_{P3} = 0.17532 in. (0.4453 cm)	PSUBD3 = P_{d3} = 77
RP4 = r_{P4} = 0.05844 in. (0.1484 cm)	J3 = 0.90
ACG3 = a_{G3} = 0.17355 in. (0.4408 cm)	
ACP3 = a_{P3} = 0.05839 in. (0.1483 cm)	
RHOG3 = ρ_{G3} = 0.02805 in. (0.0712 cm)	
RHOP3 = ρ_{P3} = 0.00909 in. (0.0231 cm)	
TG3 = t_{G3} = 0.02058 in. (0.0523 cm)	
TP3 = t_{P3} = 0.01362 in. (0.0346 cm)	
NG3 = n_{G3} = 27	
NP4 = n_{P4} = 9	

In addition

MU = μ = 0.2
 RPM = 1000
 M1 = m_1 = 0.12×10^{-3} lb-sec²/in. (2.101×10^{-2} kg)
 M2 = m_2 = 0.85×10^{-5} lb-sec²/in. (1.488×10^{-3} kg)
 M3 = m_3 = 0.34×10^{-5} lb-sec²/in. (5.953×10^{-4} kg)
 M4 = m_4 = 0.15×10^{-5} lb-sec²/in. (2.626×10^{-4} kg)
 R1 = R_1 = 0.225 in. (0.572 cm)

R2 = R_2 = 0.436 in. (1.107 cm)
 R3 = R_3 = 0.504 in. (1.280 cm)
 R4 = R_4 = 0.520 in. (1.321 cm)
 RH01 = ρ_1 = 0.062 in. (0.157 cm)
 RH02 = ρ_2 = 0.025 in. (0.064 cm)
 RH03 = ρ_3 = 0.018 in. (0.046 cm)
 RH04 = ρ_4 = 0.016 in. (0.041 cm)
 MD = rad^2 = $0.275 \times 10^{-5} \text{ lb-sec}^2\text{-in.}$ ($3.105 \times 10^{-7} \text{ kg-m}^2$)
 K = 25

Computed Values

At the beginning of the output, one finds $\text{MIN} = M_{1n}$. Subsequently, the following are listed for each mesh:

f_{p1} , the length of the pinion flats
 β_1 , the fuze body pivot to pivot line angles
 ψ_{T1} and ϕ_{T1} , the transition angles
 ϕ_{I1} and ψ_{I1} , the earliest angles
 ϕ_{F1} and ψ_{F1} , the latest angles

Finally, for the full range of the input angle ϕ_1 , the point efficiency POINTEF is listed, in addition to other parameters which are useful for checking purposes. Note that DPSI1 , DPSI2 and DPSI3 represent $\dot{\psi}_1$, $\dot{\psi}_2$, $\dot{\psi}_3$, respectively. The cycle efficiency CYCLEFF is found at the end of the output.

Computer program CLOCK3

PROGRAM CLOCK3	74/74	OUT=1	FTW 4.6420	07/31/79	08.15.34	PAGE 1
1			PROGRAM CLOCK3(INPUT,OUTPUT,TAPE=INPUT,TAPE=OUTPUT)	A 1		
	C		POINT AND CYCLE EFFICIENCIES FOR THREE PASS CLOCK (ORIGINAL) STEP UP	A 2		
	C		GEAR TRAIN IN SPIN ENVIRONMENT	A 3		
5			REAL MU, LAMBDA1, LAMBDA2, LAMBDA3, MO4, MO41, MO42, MO43, MO44, MO45, MO46, MO4	A 4		
	C		17, MO48, LX1, LY1, L1, LX2, LY2, L2, LX3, LY3, L3, NP2, NP3, NP4, NG1, NG2, NG3, MI	A 5		
			2M, MT, M2, M3, M4, MTOT, MO, LL1, LL2, LL3, K, J1, J2, J3, J4, J5	A 6		
10			1 READ (5,61) PSUBO1, PSUBO2, PSUBO3, NG1, NP2, NG2, NP3, NG3, NP4	A 7		
			READ (5,64) MU, RPM, CAPRP1, CAPRP2, CAPRP3, RP2, RP3, RP4, ACG1, ACG2, ACG3	A 8		
			1, ACP1, ACP2, ACP3, ISTOP	A 9		
			READ (5,82) R1, R2, R3, R4	A 10		
			READ (5,82) RHOG1, RHOG2, RHOG3, RHOP1, RHOP2, RHOP3	A 11		
15			READ (5,63) TG1, TG2, TG3, TP1, TP2, TP3	A 12		
			READ (5,85) M1, M2, M3, M4	A 13		
			READ (5,65) RHO1, RHO2, RHO3, RHO4, MO, K, J1, J2, J3	A 14		
			P1=3.14159	A 15		
			Z=PI/180.	A 16		
20			OMEGA=RP4*2.*PI/60.	A 17		
			OM2=OMEGA*OMEGA	A 18		
			PHOTO1=-1.	A 19		
	C		COMPUTATION OF GEAR TOOTH PARAMETERS	A 20		
25			CXG1=RHOG1-TG1/2.	A 21		
			DELG1=ASIN(CXG1/CAPRP1)	A 22		
			CXP1=RHOP1-TP1/2.	A 23		
			DELPI=ASIN(CXP1/RP2)	A 24		
30			GAMMP1=ASIN(RHOP1/RP2)	A 25		
			ALPHI1=GAMMP1-DELP1	A 26		
			FP1=ACP1-COS(GAMMP1)	A 27		
			B1=CAPRP1+RP2	A 28		
			CXG2=RHOG2-TG2/2.	A 29		
35			DELG2=ASIN(CXG2/CAPRP2)	A 30		
			CXP2=RHOP2-TP2/2.	A 31		
			DELP2=ASIN(CXP2/RP3)	A 32		
			GAMMP2=ASIN(RHOP2/RP3)	A 33		
			ALPHI2=GAMMP2-DELP2	A 34		
40			FP2=ACP2-COS(GAMMP2)	A 35		
			B2=CAPRP2+RP3	A 36		
			CXG3=RHOG3-TG3/2.	A 37		
			DELG3=ASIN(CXG3/CAPRP3)	A 38		
			CXP3=RHOP3-TP3/2.	A 39		
45			DELP3=ASIN(CXP3/RP4)	A 40		
			GAMMP3=ASIN(RHOP3/RP4)	A 41		
			ALPHI3=GAMMP3-DELP3	A 42		
			FP3=ACP3-COS(GAMMP3)	A 43		
			B3=CAPRP3+RP4	A 44		
50			COMPUTATION OF MIN, GAMMAS AND BETAS	A 45		
	C		MIN=40-OM2	A 46		
	C		DELTA2=ACOS((((CAPRP1+RP2)*(CAPRP1+RP2)+R1*R1-R2*R2)/(2.*R1*(CAPRP1	A 47		
				A 48		
				A 49		
				A 50		
				A 51		
				A 52		
				A 53		

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Computer program CLOCK3 (cont)

PROGRAM CLOCK3 74/74 OPT=1 FTM 4.6+42G 07/31/79 08.15.34 PAGE 4

```

160      GO TO 6
165      5 SIGNIF=1.
      C
      C LATEST AND EARLIEST POSSIBLE VALUES OF PHI AND PSI FOR MESH 1
      C
      6 DO 7 I=1,200G
        PHID1=PHI1D-(I-1.)/100.
        PHI1=PHID1+Z
        A1F=ACG1+COS(PHI1+DELGI+ALPHP1)-B1+COS(BETA1+ALPHP1)
        B1F=-ACG1+SIN(PHI1+DELGI+ALPHP1)+B1+SIN(BETA1+ALPHP1)
        C1F=RHOG1
        ROOT1F=A1F+A1F+B1F+B1F-C1F+C1F
        Y1F=B1F+C1F
        X1F=B1F+C1F
        PSI1F=2.*ATAN2(Y1F,X1F)
        IF (PSI1F.LT.0.) PSI1F=PSI1F+2.*PI
        LX1=B1+COS(BETA1)+ACP1+COS(PSI1F-DPSI1+DELPI)-ACG1+COS(PHI1+DPHI1+
        1DELGI)
        LY1=B1+SIN(BETA1)+ACP1+SIN(PSI1F-DPSI1+DELPI)-ACG1+SIN(PHI1+DPHI1+
        1DELGI)
        LL1=SQRT(LX1*LX1+LY1*LY1)
        DELEL1=LL1-L1
        IF (DELEL1.LE.0.) GO TO 8
      7 CONTINUE
      8 PHI1F=PHI1
        PSI1F=PSI1F
        PHI11=PHI1F+DPHI1
        PSI11=PSI1F+DPSI1
        ZF (PSI11-LT.0.) PSI11=PSI11+2.*PI
        PHI11D=PHI11/Z
        PSI11D=PSI11/Z
        PHI1FD=PHI1F/Z
        PSI1FD=PSI1F/Z
        WRITE (6,74) PHI11D,PSI11D,PHI1FD,PSI1FD
      C
      C DETERMINATION OF CORRECT SIGN FOR ROUND ON ROUND REGIME OF MESH 1
      C
        A1R=ACG1+SIN(PHI11+DELGI+DELPI)-B1+SIN(BETA1+DELPI)
        B1R=ACG1+COS(PHI11+DELGI+DELPI)-B1+COS(BETA1+DELPI)
        C1R={ACP1+ACP1+ACG1+ACG1+B1+B1-L1-L1-2.*ACG1+B1+COS(PHI11+DELGI-DE
        1TAT11)/(2.*ACPI)
        ROOT1R=A1R+A1R+B1R+B1R-C1R+C1R
        Y1R=A1R+SQRT(ROOT1R)
        X1R=B1R+C1R
        PSI1R1=2.*ATAN2(Y1R,X1R)
        PSI1R2=2.*ATAN2(Y1R2,X1R)
        IF (PSI1R1-LT.0.) PSI1R1=PSI1R1+2.*PI
        IF (PSI1R2-LT.0.) PSI1R2=PSI1R2+2.*PI
        IF (ABS(PSI11-PSI1R1)-LT.ABS(PSI11-PSI1R2)) GO TO 9
        SIGN1R=-1.
        GO TO 10
      9 SIGN1R=1.

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PROGRAM#	CLOCK3	74/74	OPT=1	F#N	4.6+420	07/31/79	08.15.34	PAGE	5
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Computer program CLOCK3 (cont.)

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PROGRAM CLOCK3 74/74 OPT=1

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266 A 266
267 A 267
268 A 268
269 A 269
270 A 270
271 A 271
272 A 272
273 A 273
274 A 274
275 A 275
276 A 276
277 A 277
278 A 278
279 A 279
280 A 280
281 A 281
282 A 282
283 A 283
284 A 284
285 A 285
286 A 286
287 A 287
288 A 288
289 A 289
290 A 290
291 A 291
292 A 292
293 A 293
294 A 294
295 A 295
296 A 296
297 A 297
298 A 298
299 A 299
300 A 300
301 A 301
302 A 302
303 A 303
304 A 304
305 A 305
306 A 306
307 A 307
308 A 308
309 A 309
310 A 310
311 A 311
312 A 312
313 A 313
314 A 314
315 A 315
316 A 316
317 A 317
318 A 318

C2F=-RHOG2
ROOT2F=A2F-A2F*B2F*B2F-C2F*C2F
Y2F1=A2F+SQRT(ROOT2F)
Y2F2=A2F-SQRT(ROOT2F)
X2F=B2F+C2F
PSI2F1=2.*ATAN2(Y2F1,X2F)
PSI2F2=2.*ATAN2(Y2F2,X2F)
IF (PSI2F1.LT.0.) PSI2F1=PSI2F1+2.*PI
IF (PSI2F2.LT.0.) PSI2F2=PSI2F2+2.*PI
IF (ABS(PSI2F1-PSI2T).LT.ABS(PSI2F2-PSI2T)) GO TO 14
PSI2FD=PSI2F1/Z
PSI2FD=PSI2F2/Z
SIG2F=-1.
GO TO 15
14 SIG2F=1.
C
C LATEST AND EARLIEST POSSIBLE VALUES OF PHI AND PSI FOR MESH 2
C
15 DO 16 I=1,1000
PHI2=PHI2TD+(1-1.)/100.
PHI2=PHI2D-Z
A2F=ACG2-COS(PHI2-DELG2-ALPH2)-B2*COS(BETA2-ALPH2)
B2F=-ACG2*SIN(PHI2-DELG2-ALPH2)+B2*SIN(BETA2-ALPH2)
C2F=-RHOG2
ROOT2F=A2F+A2F*B2F*B2F-C2F*C2F
Y2F=A2F+SIGN2F*SQRT(ROOT2F)
X2F=C2F+C2F
PSI2F=2.*ATAN2(Y2F,X2F)
IF (PSI2F.LT.0.) PSI2F=PSI2F+2.*PI
LX2=B2*COS(BETA2)+ACP2-COS(PSI2F+DPSI2-DEL2)-ACG2-COS(PHI2-DPHI2-DEL2)
LY2=B2*SIN(BETA2)+ACP2-SIN(PSI2F+DPSI2-DEL2)-ACG2-SIN(PHI2-DPHI2-DEL2)
LL2=SQRT(LX2*LX2+LY2*LY2)
DELE2=LL2-L2
IF (DELE2.LE.0.) GO TO 17
16 CONTINUE
17 PHI2F=PHI2
PSI2FF=PSI2F
PHI2I=PHI2F-DPHI2
PSI2I=PSI2FF-DPSI2
IF (PSI2I.GT.2.*PI) PSI2I=PSI2I-2.*PI
PHI2ID=PHI2I/Z
PSI2ID=PSI2I/Z
PHI2FD=PHI2F/Z
PSI2FD=PSI2F/Z
WRITE (6,77) PHI2ID,PSI2ID,PHI2FD,PSI2FD
C
C DETERMINATION OF CORRECT SIGN FOR ROUND ON ROUND REGIME OF MESH 2
C
C
A2R=B2*SIN(BETA2+DEL2)-ACG2-SIN(PHI2I-DEL2+DEL2)
B2R=B2*COS(BETA2+DEL2)-ACG2-COS(PHI2I-DEL2+DEL2)
C2R=(L2-L2-B2-ACG2-ACG2-ACP2+ACP2+2.*ACG2*B2+COS(PHI2I-DEL2+DEL2)

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Computer program CLOCK3 (cont)

PROGRAM CLOCK3 74/74 OPT=1 FTN 4.6+420 07/31/79 08.15.34 PAGE 8

```

21  STOP
   PHI3T=PHI3T2
   PSI3T=PSI3T2
22  IF (PHI3T-1.E.0.) PHI3T=PHI3T+2.*PI
   IF (PSI3T-1.E.0.) PSI3T=PSI3T+2.*PI
   PHI3TD=PHI3T/Z
   PSI3TD=PSI3T/Z
   WRITE (6,79) PHI3TD,PSI3TD
380  C
   C DETERMINATION OF CORRECT SIGN FOR ROUND CN FLAT REGIME OF MESH 3
   C
   A3F=ACG3-COS(PHI3T+DELC3+ALPHP3)-B3-COS(BETA3+ALPHP3)
   B3F=-ACG3-SIN(PHI3T+DELC3+ALPHP3)+B3-SIN(BETA3+ALPHP3)
   C3F=RHOG3
   ROOT3F=A3F+A3F*B3F+B3F-C3F+C3F
   Y3F1=A3F+SQRT(ROOT3F)
   Y3F2=A3F-SQRT(ROOT3F)
   X3F=B3F+C3F
   PSI3F1=2.*ATAN2(Y3F1,X3F)
   PSI3F2=2.*ATAN2(Y3F2,X3F)
   IF (PSI3F1-1.E.0.) PSI3F1=PSI3F1+2.*PI
   IF (PSI3F2-1.E.0.) PSI3F2=PSI3F2+2.*PI
   IF (ABS(PSI3F1-PSI3T)-1.E.0.) PSI3F1=PSI3T
   IF (ABS(PSI3F2-PSI3T)-1.E.0.) PSI3F2=PSI3T
   GO TO 24
395  SIGN3F=-1.
   GO TO 24
23  SIGN3F=1.
   C
   C LATEST AND EARLIEST POSSIBLE VALUES OF PHI AND PSI FOR MESH 3
   C
24  DU 25 I=1,2000
   PHID3=PHI3TD-(1-I.)/100.
   PHI3=PHID3+Z
   A3F=ACG3-COS(PHI3+DELC3+ALPHP3)-B3-COS(BETA3+ALPHP3)
   B3F=-ACG3-SIN(PHI3+DELC3+ALPHP3)+B3-SIN(BETA3+ALPHP3)
   C3F=RHOG3
   ROOT3F=A3F+A3F*B3F+B3F-C3F+C3F
   Y3F1=A3F+SQRT(ROOT3F)
   Y3F2=A3F-SQRT(ROOT3F)
   X3F=B3F+C3F
   PSI3F1=2.*ATAN2(Y3F1,X3F)
   PSI3F2=2.*ATAN2(Y3F2,X3F)
   IF (PSI3F1-1.E.0.) PSI3F1=PSI3F1+2.*PI
   IF (PSI3F2-1.E.0.) PSI3F2=PSI3F2+2.*PI
   LX3=B3-COS(BETA3)+ACP3-COS(PSI3F-DPSI3+DELP3)-ACG3-COS(PHI3+DPHI3+
10ELG3)
   LY3=B3-SIN(BETA3)+ACP3-SIN(PSI3F-DPSI3+DELP3)-ACG3-SIN(PHI3+DPHI3+
10ELG3)
   LL3=SQRT(LX3+LY3+LY3)
   DELEL3=LL3-L3
   IF (DELEL3.LE.0.) GO TO 26
25  CONTINUE
26  PHI3F=PHI3
   PSI3F=PSI3F
   PHI3I=PHI3F+DPHI3
   PSI3I=PSI3F+DPSI3
   IF (PSI3I-1.E.0.) PSI3I=PSI3I+2.*PI

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Computer program CLOCK3 (cont)

PROGRAM CLOCK3 74/74 OPT=1 FTN 4-G+420 07/31/79 08.15.34 PAGE 9

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425 IF (PSI31.LT.0.) PSI31=PSI31+2.*PI
    PHI3D=PHI31/Z
    PSI3D=PSI31/Z
    PHI3F=PHI3F/Z
    PSI3F=PSI3F/Z
    WRITE (6,80) PHI3D,PSI3D,PHI3F,PSI3F
430
C
C
C
    DETERMINATION OF CORRECT SIGN OF ROUND ON ROUND REGIME FOR MESH 3
433
434 A32=CCG3*SIN(PHI31+DELG3-DELP3)-B3*SIN(BETA3-DELP3)
435 B3R=ACG3*CCG3*(PHI31+DELG3-DELP3)-B3*CCG3*(BETA3-DELP3)
436 C3R=(ACG3*ACG3+ACG3*B3-L3-L3-2.*ACG3*B3*CCG3*(PHI31+DELG3-DE
    1TA3))/12.-ACG3
437
438 ROOT3R=A3R*A3R+B3R*B3R-C3R*C3R
439 Y3R1=A3R*SQR1(ROOT3R)
440 X3R=B3R+C3R
    PSI3R1=2.*ATAN2(Y3R1,X3R)
    PSI3R2=2.*ATAN2(Y3R2,X3R)
    IF (PSI3R1.LT.0.) PSI3R1=PSI3R1+2.*PI
445 IF (PSI3R2.LT.0.) PSI3R2=PSI3R2+2.*PI
    IF (ABS(PSI31-PSI3R1).LT.ABS(PSI31-PSI3R2)) GO TO 27
    SIG=1R=-1.
    GO TO 28
27 SIGNJR=1.
C
C
C
    GEAR TRAIN MOTION MODEL, KINEMATICS
28 DDPHI1=NP2*NP3*(PHI31-PHI3F)/(K*NG1*NG2)
    PH1A=PHI11*(PH1F-PHI11)*J1
    PHI1=PH1A+DDPHI1
    J4=0.
    J5=0.
    WRITE (6,52)
29 PHI1=PHI1+DDPHI1
    IF (PHI1.LE.PHI1F) J5=1.
    IF (PHI1.LE.PHI1F) PHI1=PHI11
    PHI1D=PHI1/Z
    IF ((J5.EQ.1..AND.PHI1.LE.PHI1A+DDPHI1).OR.(J1.EQ.0..AND.PHI1.LE.P
    1HI1F+DDPHI1)) GO TO 45
C
C
C
    MESH 1
460
465
C
C
C
    IF (PHI1.LE.PHI11) GO TO 30
    AIR=ACG1*SIN(PHI1+DELG1-DELP1)-B1*SIN(BETA1-DELP1)
    B1R=ACG1*CCG3*(PHI1+DELG1-DELP1)-B1*CCG3*(BETA1-DELP1)
    C1R=(ACG1*ACG1+ACG1*B1-L1-L1-2.*ACG1*B1*CCG3*(PHI1+DELG1-DE
    1A1))/12.-ACG1
470
    ROOT1R=A1R*A1R+B1R*B1R-C1R*C1R
    Y1R=A1R*SQR1(ROOT1R)
    X1R=B1R+C1R
    PSI1=2.*ATAN2(Y1R,X1R)
    IF (PSI1.LT.0.) PSI1=PSI1+2.*PI
475

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533	A 531	IF (ABS(PHI2-PHI21)).LT..0001) PSI2P=PSI21	A 536
533	A 532	IF (J4.EQ.0.) PS12P=PS12	A 537
533	A 533	SLAM2=(B2*SIN(BETA2)+ACP2*SIN(PSI2-DEL2)-ACG2*SIN(PHI2-DEL2))/L2	A 539
534	A 534	CLAM2=(B2+COS(BETA2)+ACP2+COS(PSI2-DEL2)-ACG2+COS(PHI2-DEL2))/L2	A 540
535	A 535	LAMDA2=ATAN2(SLAM2,CLAM2)	A 541
535	A 536	IF (LAMDA2.LT.0.) LAMDA2=LAMDA2+2.*PI	A 542
537	A 537	PHO212=PSO21	A 543
537	A 538	PSO212=PHO212+ACG2*(-SIN(PHI2-PSI2-DEL2+DEL2)-B2/ACP2*SIN(PHI2-D	A 544
539	A 539	ELG2-BETA2))/(A2R-COS(PSI2)-B2R+SIN(PSI21))	A 545
540	A 540	VST12=PHO212*(ACG2+COS(PHI2-DEL2-LAMDA21+RHOG2))-PSO212*(ACP2+COS(	A 546
541	A 541	PS12-DEL2-LAMDA2)-RHOP2)	A 547
542	A 542	S2R=VST2R/ABS(VST2R)	A 548
543	A 543	CO TO 33	A 549
545	A 545	32 A2F=ACG2+COS(PHI2-DEL2-ALPH2)-B2+COS(BETA2-ALPH2)	A 550
545	A 546	B2F=-ACG2-SIN(PHI2-DEL2-ALPH2)+B2*SIN(BETA2-ALPH2)	A 551
546	A 547	C2F=-RHOG2	A 552
547	A 548	RQ212F=A2F+A2F+B2F-B2F-C2F+C2F	A 553
548	A 549	Y2F=A2F+SIGN2F*SORT(ROOT2F)	A 554
549	A 550	X2F=U2F+C2F	A 555
550	A 551	PS1212=ATAN2(Y2F,X2F)	A 556
551	A 552	IF (PS12.LT.0.) PS12=PS12+2.*PI	A 557
552	A 553	IF (PS12.GT.2.*PI) PS12=PS12-2.*PI	A 559
553	A 554	IF (J4.EQ.0.) PS12P=PS12	A 560
554	A 555	PS1212=PS12/Z	A 561
555	A 556	G21=ACG2-SIN(PHI2-DEL2)-RHOG2+COS(PSI2+ALPH2)-B2+SIN(BETA2))/(SIN	A 562
555	A 557	1(PS12+ALPH2)	A 563
556	A 558	PHO212=PSO21	A 564
556	A 559	PSO212=(PHO212+ACG2+COS(PHI2-DEL2-ALPH2-PS121))/(A2F+COS(PS12)-B2	A 565
556	A 560	1F*SIN(PS121))	A 566
556	A 561	VST12F=PHO212*(ACG2+SIN(PS12+ALPH2-PS12+DEL2)+RHOG2)	A 567
556	A 562	S2F=VST12F/ABS(VST12F)	A 568
556	A 563	MESH 3	A 569
556	A 564		A 570
556	A 565		A 571
556	A 566	33 DDPHI3=PS12-PS12P	A 572
556	A 567	IF (J4.EQ.0.) PHI3=PHI31+(PHI3F-PHI31)*J3	A 573
556	A 568	PHI3=PHI3+DDPHI3	A 574
556	A 569	IF (PHI3.GT.2.*PI) PHI3=PHI3-2.*PI	A 575
556	A 570	PS1212=PS12	A 576
556	A 571	IF (PHI3.LT.PHI3F) PHI3=PHI31	A 577
556	A 572	PHI3O=PHI3/Z	A 578
556	A 573	IF (PHI3.LE.PHI31) GO TO 34	A 579
556	A 574	A3R=ACG3+S1M(PHI3+DEL3-DEL2)-B3*SIN(BETA3-DEL3)	A 580
556	A 575	B3R=ACG3+COS(PHI3+DEL3-DEL2)-B3+COS(BETA3-DEL3)	A 581
556	A 576	C3R=(ACP3+ACP3+ACG3+ACG3+83/83-L3+L3-2.*ACG3+83+COS(PHI3+DEL3-BET	A 582
556	A 577	1A31)/(2.*CP3)	A 583
556	A 578	RQO12R=A3R+A3R+B3R-B3R-C3R+C3R	
556	A 579	Y3R=A3R+SIGN3R*SORT(ROOT3R)	
556	A 580	X3R=B3R+C3R	
556	A 581	PS1312=ATAN2(Y3R,X3R)	
556	A 582	IF (PS13.LT.0.) PS13=PS13+2.*PI	
556	A 583	PS13O=PS13/Z	
556	A 584	SLAM3=(B3+SIN(BETA3)+ACP3*SIN(PS13+DEL3)-ACG3+SIN(PHI3+DEL3))/L3	

Computer program CLOCK3 (cont)

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585 CLAW3=(B3+COS(BETA3)+ACP3+COS(PSI3+DELPH3)-ALG3+COS(PHI3+DELG3))/L3
    LAMDA3=ATAN2(SLAW3,CLAW3)
    IF (LAMDA3.LT.0.0) LAMDA3=LAMDA3+2.*PI
    PHG313=PS3012
    PS3013=PHG313+ACG3-(B3/ACP3+SIN(PHI3+DELG3-BETA3)+SIN(PHI3-PSI3+DE
    LCG3-DELPH3))/(AG3+COS(PSI3)-E3R+SIN(PSI3))
    VST3R=PHG313*(ACG3+COS(PHI3+DELG3-LAMDA3)+RHO33)-PS3013*(ACP3+COS(
    PSI3-DELPH3-LAMDA3)-RHOP3)
    S3R=VST3R/ABS(VST3R)
    GO TO 35

34 A3F=ACG3+COS(PHI3+DELG3+ALPH3)-B3+COS(BETA3+ALPH3)
    B3F=ACG3+SIN(PHI3+DELG3+ALPH3)+B3*SIN(BETA3+ALPH3)
    C3F=RHOG3
    ROOT3F=A3F+B3F+B3F-C3F-C3F
    Y3F=A3F+SIGN3F*SQRT(ROOT3F)
    X3F=B3F+C3F
    PS13=2.*ATAN2(Y3F,X3F)
    IF (PS13.LT.0.) PS13=PS13+2.*PI
    PSI30=PS13/2
    G3=ACG3+SIN(PHI3+DELG3)+RHOG3+COS(PSI3-ALPH3)-B3*SIN(BETA3))/SIN
    1(PS13-ALPH3)
    PHG313=PS3012
    PS3013=PHG313+ACG3+COS(PHI3-PSI3+DELG3+ALPH3)/(A3F+COS(PSI3)-B3F+
    SIN(PS13))
    VST3R=PHG313*(ACG3+SIN(PSI3-ALPH3)-PHI3-DELG3)-RHOG3
    S3F=VST3R/ABS(VST3R)

C
C
C
35 DN=1.+XU-XU
    A1=ABS((XU+SIN(GAMMA4)+COS(GAMMA4))/DN)
    A2=ABS((XU+S3R-1.-SIN(LAMDA3)-(1.+XU-XU)*S3R)*COS(LAMDA3))/DN)
    A3=ABS((SIN(GAMMA4)-XU)*COS(GAMMA4))/DN)
    A4=ABS((1.-XU-XU*S3R)*SIN(LAMDA3)+XU*(S3R-1.)*COS(LAMDA3))/DN)
    A5=ABS((1.-XU-XU*S3R)*COS(LAMDA3)-XU*(1.+S3R)*SIN(LAMDA3))/DN)
    A6=ABS((XU*(1.+S3R)+SIN(LAMDA2)-(1.-XU-XU)*S2R)*COS(LAMDA2))/DN)
    A7=ABS((XU-SIN(GAMMA3)-COS(GAMMA3))/DN)
    A8=ABS((1.-XU-XU*S3R)*SIN(LAMDA3)+XU*(1.+S3R)*COS(LAMDA3))/DN)
    A9=ABS((XU-XU*S2R-1.-SIN(LAMDA2)-XU*(1.+S2R)*COS(LAMDA2))/DN)
    A10=ABS((SIN(GAMMA3)+XU)*COS(GAMMA3))/DN)
    A11=ABS((1.-XU-XU*S2R)*COS(LAMDA2)-XU*(S2R-1.)*SIN(LAMDA2))/DN)
    A12=ABS((XU*(S1R-1.)*SIN(LAMDA1)-(1.-XU-XU)*S1R)*COS(LAMDA1))/DN)
    A13=ABS((-COS(GAMMA2)-XU*SIN(GAMMA2))/DN)
    A14=ABS((1.-XU-XU*S2R)*SIN(LAMDA2)-XU*(1.-S2R)*COS(LAMDA2))/DN)
    A15=ABS((XU*(1.-S1R)*COS(LAMDA1)-(1.-XU-XU)*S1R)*SIN(LAMDA1))/DN)
    A16=ABS((XU-COS(GAMMA2)-SIN(GAMMA2))/DN)
    A17=ABS((1.-XU-XU*S1R)*COS(LAMDA1)-XU*(1.+S1R)*SIN(LAMDA1))/DN)
    A18=ABS(1./DN)
    A19=ABS((1.-XU-XU*S1R)*SIN(LAMDA1)+XU*(1.+S1R)*COS(LAMDA1))/DN)
    A20=ABS(XU/DN)
    A21=ABS((XU*(1.-S2R)+SIN(LAMDA2)+(1.-XU-XU)*S2R)*COS(LAMDA2))/DN)
    A22=ABS(((1.-XU-XU)*S1F)+SIN(PSI1-ALPH1)-XU*(1.+S1F)*COS(PSI1-ALPH
    1PI))/DN)

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Computer program CLOCK3 (cont)

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FTN 4.6+420

OPT=1

PROGRAM CLOCK3

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64C      A23=ABS((MU*SIN(GAMMA2))+COS(GAMMA2))/DN)
        A24=ABS((1.-MU*MU*S2R)*SIN(LAMDA2)-MU*(1.-S2R)*COS(LAMDA2))/DN)
        A25=ABS((-MU*(1.+S1F)+SIN(PSI1-ALPH1)+(MU*MU*S1F-1.)*COS(PSI1-ALP
1P21))/DN)
        A26=ABS((-SIN(GAMMA2)+MU*COS(GAMMA2))/DN)
        A27=ABS((-1.-MU*MU*S1F)-SIN(PSI1-ALPH1)+MU*(S1F-1.)*COS(PSI1-ALP
1P11))/DN)
        A28=ABS(1./DN)
        A29=ABS((MU*(S1F-1.)*SIN(PSI1-ALPH1)+(1.-MU*MU*S1F)*COS(PSI1-ALPH
1P11))/DN)
        A30=ABS(MU/DN)
        A31=ABS(((1.-MU*MU*S3R)*COS(LAMDA3)-MU*(1.+S3R)*SIN(LAMDA3))/DN)
        A32=ABS((-MU*(1.+S2F)+COS(PSI2+ALPH2)-(1.-MU*MU*S2F)*SIN(PSI2+ALP
1P21))/DN)
        A33=ABS((MU*SIN(GAMMA3)-COS(GAMMA3))/DN)
        A34=ABS((MU*(1.+S3R)*COS(LAMDA3)+(1.-MU*MU*S3R)*SIN(LAMDA3))/DN)
        A35=ABS(((1.-MU*MU*S2F)*COS(PSI2+ALPH2)-MU*(1.+S2F)*SIN(PSI2+ALPH
1P21))/DN)
        A36=ABS((SIN(GAMMA3)+MU*COS(GAMMA3))/DN)
        A37=ABS(((1.-MU*MU*S2F)*SIN(PSI2+ALPH2)+MU*(S2F-1.)*COS(PSI2+ALPH
1P21))/DN)
        A38=ABS(((1.-MU*MU*S1F)*SIN(PSI1-ALPH1)-MU*(1.+S1F)*COS(PSI1-ALPH
1P11))/DN)
        A39=ABS((MU*SIN(GAMMA2)+COS(GAMMA2))/DN)
        A40=ABS((MU*(S2F-1.)*SIN(PSI2+ALPH2)-(1.-MU*MU*S2F)*COS(PSI2+ALPH
1P21))/DN)
        A41=ABS((-MU*(1.+S1F)+SIN(PSI1-ALPH1)+(MU*MU*S1F-1.)*COS(PSI1-ALP
1P11))/DN)
        A42=ABS((MU*COS(GAMMA2)-SIN(GAMMA2))/DN)
        A43=ABS(((1.-MU*MU*S2F)*SIN(PSI2+ALPH2)-MU*(1.-S2F)*COS(PSI2+ALPH
1P21))/DN)
        A44=ABS((MU*(S1R-1.)*SIN(LAMDA1)-(1.-MU*MU*S1R)*COS(LAMDA1))/DN)
        A45=ABS((MU*SIN(GAMMA2)+COS(GAMMA2))/DN)
        A46=ABS((MU*(S2F-1.)*SIN(PSI2+ALPH2)-(1.-MU*MU*S2F)*COS(PSI2+ALPH
1P21))/DN)
        A47=ABS((-1.-MU*MU*S1R)*SIN(LAMDA1)+MU*(1.-S1R)*COS(LAMDA1))/DN)
        A48=ABS((-SIN(GAMMA2)+MU*COS(GAMMA2))/DN)
        A49=ABS(((1.-MU*MU*S3F)*SIN(PSI3-ALPH3)-MU*(1.+S3F)*COS(PSI3-ALPH
1P31))/DN)
        A50=ABS((-MU*SIN(GAMMA4)-COS(GAMMA4))/DN)
        A51=ABS((-MU*(1.+S3F)+SIN(PSI3-ALPH3)-(1.-MU*MU*S3F)*COS(PSI3-ALP
1P31))/DN)
        A52=ABS((-SIN(GAMMA4)+MU*COS(GAMMA4))/DN)
        A53=ABS((-1.-MU*MU*S3F)*SIN(PSI3-ALPH3)+MU*(S3F-1.)*COS(PSI3-ALP
1P31))/DN)
        A54=ABS((MU*MU*S2F-1.)*SIN(PSI2+ALPH2)-MU*(1.+S2F)*COS(PSI2+ALPH
1P21))/DN)
        A55=ABS((MU*SIN(GAMMA3)-COS(GAMMA3))/DN)
        A56=ABS((MU*(S3F-1.)*SIN(PSI3-ALPH3)+(1.-MU*MU*S3F)*COS(PSI3-ALPH
1P31))/DN)
        A57=ABS((-MU*(1.+S2F)+SIN(PSI2+ALPH2)+(1.-MU*MU*S2F)*COS(PSI2+ALP
1P21))/DN)
        A58=ABS((-SIN(GAMMA3)-MU*COS(GAMMA3))/DN)

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Computer program CLOCK3 (cont.)

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690 A59=ABS((-1.+(MU*EU-S3F)*SIN(PSI3-ALPH3)+MU*(S3F-1.))*COS(PSI3-ALP
    1PH3))/DN) A 690
A60=ABS((MU*(1.+S2R)*SIN(LAMDA2)+(MU*EU*S2R-1.)*COS(LAMDA2))/DN) A 691
A61=ABS((MU*SIN(GAMMA3)-COS(GAMMA3))/DN) A 692
A62=ABS((MU*(S3F-1.)*SIN(PSI3-ALPH3)+(1.+MU*EU*S3F)*COS(PSI3-ALPH
    1PH3))/DN) A 693
A63=ABS((MU*EU*S2R-1.)*SIN(LAMDA2)-MU*(1.+S2R)*COS(LAMDA2))/DN) A 694
A64=ABS((-SIN(GAMMA3)-MU*COS(GAMMA3))/DN) A 695
C1=EU*RHO4*(A1+A3) A 696
C2=ACP3*(MU*S3R*COS(PSI3+DELP3-LAMDA3)-SIN(PSI3+DELP3-LAMDA3))-MU*
    1(RHO3*S3R+RHO4*(A2+A4)) A 697
C3=EU*RHO3*(A5+A8)-MU*S3R*RHO3+ACG3*(SIN(PHI3-DELG3-LAMDA3)-MU*S3
    1R+COS(PHI3-DELG3-LAMDA3)) A 698
C4=EU*RHO3*(A7+A10) A 699
C5=EU*RHO3*(A6+A9)-MU*S2R*RHO2+ACP2*(MU*S2R*COS(PSI2-DELP2-LAMDA2
    1)-SIN(PSI2-DELP2-LAMDA2)) A 700
C6=ACG2*(SIN(PHI2-DELG2-LAMDA2)-MU*S2R*COS(PHI2-DELG2-LAMDA2))-MU*
    1RHO2*(A11+A14)-MU*RHO2*S2R A 701
C7=EU*RHO2*(A13+A16) A 702
C8=-ACPI*(SIN(PSI1+DELP1-LAMDA1)-MU*S1R*COS(PSI1+DELP1-LAMDA1))+M
    1U*RHO2*(A12+A15)+EU*S1R*RHO1 A 703
C9=EU*RHO1*(A18+A20) A 704
C10=EU*RHO1*(A17+A19)+ACG1*(SIN(PHI1+DELG1-LAMDA1)-MU*S1R*COS(PHI1
    1+DELG1-LAMDA1))-MU*S1R*RHO1 A 705
C11=ACG2*(SIN(PHI2-DELG2-LAMDA2)-MU*S2R*COS(PHI2-DELG2-LAMDA2))-MU
    1RHO2*(A21+A24)-MU*RHO2*S2R A 706
C12=EU*RHO2*(A23+A26) A 707
C13=EU*RHO2*(A22+A25) A 708
C14=EU*RHO1*(A28+A30) A 709
C15=EU*RHO1*(A27+A29)+MU*S1F*RHO1+ACG1*(MU*S1F*SIN(PHI1+DELG1-PSI
    1+ALPH1))-COS(PHI1+DELG1-PSI1+ALPH1) A 710
C16=EU*RHO3*(A31+A34)+ACG3*(SIN(PHI3+DELG3-LAMDA3)-MU*S3R*COS(PHI3
    1+DELG3-LAMDA3))-RHO3*MU*S3R A 711
C17=EU*RHO3*(A33+A36) A 712
C18=EU*RHO3*(A32+A35)-G2 A 713
C19=-MU*RHO2*(A37+A40)+ACG2*(COS(PHI2-DELG2-PSI2-ALPH2)+MU*S2F*SI
    1N(PHI2-DELG2-PSI2-ALPH2))-MU*S2F*RHO2 A 714
C20=EU*RHO2*(A39+A42) A 715
C21=-MU*RHO2*(A38+A41)+G1 A 716
C22=-MU*RHO2*(A43+A46)+ACG2*(COS(PHI2-DELG2-PSI2-ALPH2)+MU*S2F*SI
    1N(PHI2-DELG2-PSI2-ALPH2))-MU*S2F*RHO2 A 717
C23=EU*RHO2*(A45+A48) A 718
C24=-MU*RHO2*(A44+A47)+ACPI*(MU*S1R*COS(PSI1+DELP1-LAMDA1)-SIN(PSI
    1+DELP1-LAMDA1))-EU*S1R*RHO1 A 719
C25=EU*RHO4*(A50+A52) A 720
C26=-G3-MU*RHO4*(A49+A51) A 721
C27=EU*RHO3*(A53+A56)+ACG3*(-COS(PHI3+DELG3-PSI3+ALPH3)+MU*S3F*SI
    1N(PHI3+DELG3-PSI3+ALPH3))-MU*S3F*RHO3 A 722
C28=EU*RHO3*(A55+A58) A 723
C29=EU*RHO3*(A54+A57)-G2 A 724
C30=EU*RHO3*(A59+A62)-ACG3*(COS(PHI3+DELG3-PSI3+ALPH3)-MU*S3F*SI
    1N(PHI3+DELG3-PSI3+ALPH3))+MU*S3F*RHO3 A 725
C31=EU*RHO3*(A61+A64) A 726

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Computer program CLOCK3 (cont.)

PROGRAM	CLOCK3	74/74	OPT=1	FTN 4.6+420	07/31/79	08.15.34	PAGE	15
745	C			C32=RU+RHO3*(A60+A63)-ACP2*(SIN(P512-DELP2-LAMDA2)-MU+S2R-SHOP2	A 743			
	C			1-DELP2-LAMDA2))-MU+S2R-SHOP2	A 744			
	C			MOMENT CONTROL	A 745			
	C			IF ((PH11.GE.PHI11).AND.(PH12.LE.PHI12).AND.(PH13.GE.PHI13)) GO TO	A 746			
				1 36	A 747			
750				IF ((PH11.LE.PHI11).AND.(PH12.LE.PHI12).AND.(PH13.GE.PHI13)) GO TO	A 748			
				1 37	A 749			
				IF ((PH11.LE.PHI11).AND.(PH12.GE.PHI12).AND.(PH13.GE.PHI13)) GO TO	A 750			
				1 38	A 751			
				IF ((PH11.GE.PHI11).AND.(PH12.GE.PHI12).AND.(PH13.GE.PHI13)) GO TO	A 752			
755				1 39	A 753			
				IF ((PH11.GE.PHI11).AND.(PH12.GE.PHI12).AND.(PH13.GE.PHI13)) GO TO	A 754			
				1 40	A 755			
				IF ((PH11.LE.PHI11).AND.(PH12.GE.PHI12).AND.(PH13.LE.PHI13)) GO TO	A 756			
				1 41	A 757			
				IF ((PH11.GE.PHI11).AND.(PH12.GE.PHI12).AND.(PH13.LE.PHI13)) GO TO	A 758			
760				1 42	A 759			
				IF ((PH11.GE.PHI11).AND.(PH12.LE.PHI12).AND.(PH13.LE.PHI13)) GO TO	A 760			
				1 43	A 761			
				IF ((PH11.LE.PHI11).AND.(PH12.LE.PHI12).AND.(PH13.LE.PHI13)) GO TO	A 762			
				1 44	A 763			
765	C			MOMENT EXPRESSIONS	A 764			
	C			36 MD41=MIN-C2-C5-C8/(C3-C6-C10)-04-C1-02-C2-C5-C7/(C3-C6)-03-C2-C4/C	A 765			
	C			13-Q1-C2-C5-C8-C9/(C3-C6-C10)	A 766			
				MD4=MD41	A 767			
770				POINTEF=ABS(PSDOT3)*MD4/MIN	A 768			
				WRITE (6,53) PH11D,PH12D,PH13D,PS11D,PS12D,PS13D,PSDOT1,PSDOT2,PSD	A 769			
				1013,S1R,S2R,S3R,POINTEF	A 770			
				GO TO 44	A 771			
775				37 MD42=MIN-C2-C5-C13/(C3-C11-C15)-01-C2-C5-C13-C14/(C3-C11-C15)-02-C	A 772			
				12-C5-C12/(C3-C11)-03-C2-C4/C3-Q4-C1	A 773			
				MD4=MD42	A 774			
				POINTEF=ABS(PSDOT3)*MD4/MIN	A 775			
				WRITE (6,54) PH11D,PH12D,PH13D,PS11D,PS12D,PS13D,PSDOT1,PSDOT2,PSD	A 776			
				1013,S2R,S3R,S1F,G1,S2F,G2,POINTEF	A 777			
				GO TO 44	A 778			
780				38 MD43=MIN-C2-C18-C21/(C15-C16-C19)-01-C2-C14-C18-C21/(C15-C16-C19)-	A 779			
				102-C2-C18-C20/(C16-C19)-03-C2-C17/C16-Q4-C1	A 780			
				MD4=MD43	A 781			
				POINTEF=ABS(PSDOT3)*MD4/MIN	A 782			
				WRITE (6,55) PH11D,PH12D,PH13D,PS11D,PS12D,PS13D,PSDOT1,PSDOT2,PSD	A 783			
785				1013,S2R,S1F,G1,S2F,G2,POINTEF	A 784			
				GO TO 44	A 785			
790				39 MD44=MIN-C2-C18-C24/(C10-C16-C22)-01-C2-C9-C18-C24/(C10-C16-C22)-0	A 786			
				12-C2-C18-C23/(C16-C22)-03-C2-C17/C16-Q4-C1	A 787			
				MD4=MD44	A 788			
				POINTEF=ABS(PSDOT3)*MD4/MIN	A 789			
				WRITE (6,56) PH11D,PH12D,PH13D,PS11D,PS12D,PS13D,PSDOT1,PSDOT2,PSD	A 790			
				1013,S1R,S3R,S2F,G2,POINTEF	A 791			
				GO TO 42	A 792			
795				40 MD45=MIN-C21-C26-C29/(C15-C19-C27)-01-C14-C21-C26-C29/(C15-C19-C27	A 793			
					A 794			
					A 795			

Computer program CLOCK3 (cont.)

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74/74 OPT=1

PROGRAM CLOCK3

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1) -02-C20-C26-C29/(C19-C27)-03-C26-C28/C27-03-C25
204=0045
POINTEF=ABS(P500T3)*MO4/MIN
WRITE (6,57) PHI10,PHI20,PHI30,PSI10,PSI20,PSI30,P500T1,P500T2,P50
10T3,S1F,G1,S2F,G2,S3F,G3,POINTEF
GO TO 44
41 0046=MIN-C24-C26-C29/(C10-C22-C27)-01-C9-C24-C26-C29/(C10-C22-C27)
1-02-C23-C26-C29/(C22-C27)-03-C26-C28/C27-04-C25
004=0045
POINTEF=ABS(P500T3)*MO4/MIN
WRITE (6,58) PHI10,PHI20,PHI30,PSI10,PSI20,PSI30,P500T1,P500T2,P50
10T3,S1F,G1,S2F,G2,S3F,G3,POINTEF
GO TO 44
42 0047=MIN-C8-C26-C32/(C6-C10-C30)-01-C8-C9-C26-C32/(C6-C10-C30)-02-
1C7-C26-C32/(C6-C30)-03-C26-C31/C30-04-C25
004=0047
POINTEF=ABS(P500T3)*MO4/MIN
WRITE (6,59) PHI10,PHI20,PHI30,PSI10,PSI20,PSI30,P500T1,P500T2,P50
10T3,S1F,G1,S2F,G2,S3F,G3,POINTEF
GO TO 44
43 0048=MIN-C12-C26-C32/(C11-C15-C30)-01-C13-C14-C26-C32/(C11-C15-C30)
004=0048
POINTEF=ABS(P500T3)*MO4/MIN
WRITE (6,60) PHI10,PHI20,PHI30,PSI10,PSI20,PSI30,P500T1,P500T2,P50
10T3,S2F,S1F,G1,S3F,G3,POINTEF
44 MTOT=MTOT+POINTEF
J4=1
GO TO 29
45 CYCLEFF=MTOT*DOPIH1/(PHI1F-PHI1I)
WRITE (6,81) CYCLEFF
MTOT=0
IF (ISTOP.NE.0) GO TO 1
STOP
C
C
C
46 FORMAT (6X,9HPSI11D =,F9.4,3X,8HTEST11 =,F9.4)
47 FORMAT (6X,9HPSI11D =,F9.4,3X,8HTEST12 =,F9.4//)
48 FORMAT (6X,9HPSI21D =,F9.4,3X,8HTEST21 =,F9.4)
49 FORMAT (6X,9HPSI21D =,F9.4,3X,8HTEST22 =,F9.4//)
50 FORMAT (6X,9HPSI31D =,F9.4,3X,8HTEST31 =,F9.4)
51 FORMAT (6X,9HPSI31D =,F9.4,3X,8HTEST32 =,F9.4//)
52 FORMAT (132H0 PH11 PH12 PH13 PS11 PS12 PS13
10PS11 DP512 DP513 S1R S2R S3R S1F G1 S2F G2 S3F
2G3 POINTEF/)
53 FORMAT (6X,6(F6.2,2X),3(F5.0,2X),3(F3.0,2X),36X,F5.3)
54 FORMAT (6X,6(F6.2,2X),3(F5.0,2X),5X,3(F3.0,2X),F5.3,26X,F5.3)
55 FORMAT (6X,6(F6.2,2X),3(F5.0,2X),10X,F3.0,2X,F5.3,2X,F3.0,
12X,F5.3,14X,F5.3)
56 FORMAT (6X,6(F5.2,2X),3(F5.0,2X),F3.0,7X,F3.0,14X,F3.0,2X,F5.3,14X
1,F5.3)
57 FORMAT (6X,6(F6.2,2X),3(F5.0,2X),15X,3(F3.0,2X,F5.3,2X),F5.3)

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Computer program CLOCK3 (cont)

SUBROUTINE TRANSI	74/74	OPT=1	FTM 4.6-420	07/31/79	08.15.34	PAGE	1
1	SUBROUTINE TRANSI (RHOG,ALPHP,BETA,FP,ACG,B,DELG,Z,PSIT,PHIT,G)						1
	PI=3.14159						2
	SI=1-RHOG*COS(PSIT-ALPHP)+B*SIN(BETA)+FP*SIN(PSIT-ALPHP))/ACG						3
	CT=(RHOG*SIN(PSIT-ALPHP)+B*COS(BETA)+FP*COS(PSIT-ALPHP))/ACG						4
5	PHIT=ATAN2(SI,CT)-DELG						5
	PHINEXT=PHIT-.1*Z						6
	AF=ACG*COS(PHINEXT+DELG+ALPHP)-B*COS(BETA+ALPHP)						7
	BF=-ACG*SIN(PHINEXT+DELG+ALPHP)+B*SIN(BETA+ALPHP)						8
	CF=RHOG						9
10	ROOTF=AF+BF+CF						10
	YF1=AF+SQRT(ROOTF)						11
	YF2=AF-SQRT(ROOTF)						12
	XF=BF+CF						13
	PSINEX1=2.*ATAN2(YF1,XF)						14
15	PSINEX2=2.*ATAN2(YF2,XF)						15
	IF (PSINEX1.LT.0.) PSINEX1=PSINEX1+2.*PI						16
	IF (PSINEX2.LT.0.) PSINEX2=PSINEX2+2.*PI						17
	IF (ABS(PSINEX1-PSIT).LT.ABS(PSINEX2-PSIT)) GO TO 1						18
	PSINEX1=PSINEX2						19
20	GO TO 2						20
	1 PSINEX1=PSINEX1						21
	2 G=(ACG*SIN(PHINEXT+DELG)+RHOG*COS(PSINEX1-ALPHP)-B*SIN(BETA))/SIN(						22
	1 PSINEX1-ALPHP)						23
	RETURN						24
25	END						25-

Computer program CLOCK3 (cont)

SUBROUTINE TRANS2	74/74	DPT=1	FTN 4.6+420	07/31/79	08.15.34	PAGE	1
1	SUBROUTINE TRANS2 (RHOG, ALPH, BETA, FP, ACG, B, DELG, Z, PSIT, PHIT, G)						C 1
	PI=3.14159						C 2
	ST=(RHOG* $\cos(\text{PSIT}+\text{ALPH})$)*B* $\sin(\text{BETA})$ +FP* $\sin(\text{PSIT}+\text{ALPH})$)/ACG						C 3
	CT=(1-RHOG* $\sin(\text{PSIT}+\text{ALPH})$)*B* $\cos(\text{BETA})$ +FP* $\cos(\text{PSIT}+\text{ALPH})$)/ACG						C 4
5	PHIT=ATAN2(ST,CT)*DELG						C 5
	PHINEXT=PHIT+.1*Z						C 6
	AF=ACG* $\cos(\text{PHINEXT}-\text{DELG}-\text{ALPH})$ -B* $\cos(\text{BETA}-\text{ALPH})$						C 7
	BF=-ACG* $\sin(\text{PHINEXT}-\text{DELG}-\text{ALPH})$ +B* $\sin(\text{BETA}-\text{ALPH})$						C 8
10	CF=-RHOG						C 9
	ROOTF=AF*AF+BF*BF-CF*CF						C 10
	VF1=AF+ $\sqrt{\text{ROOTF}}$						C 11
	VF2=AF- $\sqrt{\text{ROOTF}}$						C 12
	XF=BF+CF						C 13
15	PSINEX1=2.*ATAN2(VF1,XF)						C 14
	PSINEX2=2.*ATAN2(VF2,XF)						C 15
	IF (PSINEX1-LT.0.) PSINEX1=PSINEX1+2.*PI						C 16
	IF (PSINEX2-LT.0.) PSINEX2=PSINEX2+2.*PI						C 17
	IF (ABS(PSINEX1-PSIT)-LT.ABS(PSINEX2-PSIT)) GO TO 1						C 18
20	PSINEX1=PSINEX2						C 19
	GO TO 2						C 20
	1 PSINEX1=PSINEX1						C 21
	2 G=(ACG* $\sin(\text{PHINEXT}-\text{DELG})$ -RHOG* $\cos(\text{PSINEX1}+\text{ALPH})$ -B* $\sin(\text{BETA})$)/ $\sin(\text{PSINEX1}+\text{ALPH})$						C 22
	RETURN						C 23
25	END						C 24
							C 25-

Computer program CLOCK3 (cont.)

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PSUB01 = 44. PSUB02 = 55. PSUB03 = 77.
MIN = .030157 MU = .200 RPM = 1000.
CAPRF1 = .47727 CAPRP2 = .20769 CAPRP3 = .17532
RP2 = .09091 RP3 = .06923 RP4 = .05844
ACG1 = .47343 ACG2 = .20559 ACG3 = .17355
ACP1 = .09083 ACP2 = .06917 ACP3 = .05839
NG1 = 42. NG2 = 27. NG3 = 27. NP2 = 8. NP3 = 9. NP4 = 9.
R1 = .22500 R2 = .43600 R3 = .50400 R4 = .52000
RHOG1 = .04857 RHOG2 = .03323 RHOG3 = .02805 RHOP1 = .01591 RHOP2 = .01077 RHOP3 = .00909
TG1 = .03609 TG2 = .02438 TG3 = .02058 TP1 = .02382 TP2 = .01613 TP3 = .01362
M1 = .12000E-03 M2 = .05000E-03 M3 = .34000E-05 M4 = .15000E-05
RH01 = .062 RH02 = .025 RH03 = .018 RH04 = .016
MU = .2750E-05
K = 25.0
PHOOT1 = -1.0
J1 = .90 J2 = .90 J3 = .90
FP1 = .06943 FP2 = .06833 FP3 = .05765
BETA1D = 135.8183 BETA2D = 207.7654 BETA3D = 257.3601
PSI11D = 136.2544 PSI12D = 332.4403 TEST11 = 9.0647
PSI12D = 140.2158 PSI11D = 311.7042 PHI1FD = 131.6444 PSI1FD = 356.7042
PSI21D = 337.8854 TEST12 = 43.1735
PSI22D = 12.3618 TEST22 = 8.6971
PHI21D = 207.2958 PSI22D = 12.3618
PHI22D = 200.9124 PSI21D = 31.4084 PHI2FD = 214.2458 PSI2FD = 351.4084
PSI31D = 82.7809 TEST31 = 8.6883
PSI32D = 117.2516 TEST32 = 43.1790
PHI31D = 247.6360 PSI32D = 32.7639
PHI32D = 254.2093 PSI31D = 63.7458 PHI3FD = 240.8760 PSI3FD = 103.7458

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Computer program CLOXK3 (cont)

PH11	PH12	PH13	PS11	PS12	FS13	DPS11	DPS12	DPS13	S1R	S2R	S3R	S4	G1	S2F	G2	S3F	G3	POINTEF
132.50	212.91	242.21	352.45	355.25	99.91	5.	-15.	44.					1.	1.	.063	1.	.053	.320
132.47	213.68	241.70	352.62	354.74	101.39	5.	-15.	43.					1.	1.	.063	1.	.053	.317
132.43	213.26	241.20	352.79	354.24	102.83	5.	-15.	42.					1.	1.	.063	1.	.053	.315
132.40	213.43	254.71	352.96	353.74	63.75	5.	-15.	44.					1.	1.	.063			.345
132.37	213.50	253.71	353.13	353.24	65.24	5.	-15.	44.					1.	1.	.063			.348
132.33	213.77	253.22	353.30	352.75	66.71	5.	-14.	43.					1.	1.	.063			.350
132.30	213.94	252.73	353.48	352.27	68.17	5.	-14.	43.					1.	1.	.063			.353
132.26	214.11	252.25	353.65	351.78	69.61	5.	-14.	42.					1.	1.	.063			.355
132.23	208.91	252.25	353.82	31.41	69.61	5.	-15.	45.					1.	1.	.063			.391
132.20	201.08	251.74	353.99	30.89	71.13	5.	-15.	45.					1.	1.	.063			.356
132.16	201.25	251.23	354.16	30.38	72.65	5.	-15.	45.					1.	1.	.063			.400
132.13	201.42	250.72	354.32	29.88	74.16	5.	-15.	45.					1.	1.	.063			.401
132.10	201.59	250.21	354.49	29.37	75.66	5.	-15.	44.					1.	1.	.063			.399
132.06	201.76	249.71	354.66	28.87	77.16	5.	-15.	44.					1.	1.	.063			.397
132.03	201.93	249.21	354.83	28.36	78.66	5.	-15.	44.					1.	1.	.063			.395
131.99	202.09	248.70	355.00	27.86	80.16	5.	-15.	44.					1.	1.	.063			.393
131.96	202.26	248.21	355.16	27.36	81.66	5.	-15.	44.					1.	1.	.063			.391
131.93	202.43	247.71	355.33	26.87	83.15	5.	-15.	44.					1.	1.	.063			.389
131.89	202.59	247.21	355.50	26.37	84.65	5.	-15.	44.					1.	1.	.063			.387
131.86	202.76	246.72	355.65	25.88	86.15	5.	-15.	45.					1.	1.	.063			.385
131.82	202.93	246.23	355.83	25.38	87.65	5.	-15.	45.					1.	1.	.063			.383
131.79	203.09	245.73	356.00	24.89	89.18	5.	-14.	45.					1.	1.	.063			.381
131.76	203.26	245.24	356.16	24.40	90.69	5.	-14.	45.					1.	1.	.063			.379
131.72	203.42	244.75	356.33	23.91	92.20	5.	-14.	44.					1.	1.	.063			.377
131.69	203.59	244.27	356.49	23.42	93.70	5.	-14.	44.					1.	1.	.063			.375
131.65	203.75	243.78	356.65	22.94	95.19	5.	-14.	44.					1.	1.	.063			.373
131.62	203.92	243.29	356.81	22.45	96.68	5.	-14.	44.					1.	1.	.063			.371
131.58	204.08	242.80	356.97	21.96	98.17	5.	-14.	44.					1.	1.	.063			.369
131.55	204.25	242.31	357.13	21.47	99.66	5.	-14.	44.					1.	1.	.063			.367
131.52	204.42	241.82	357.29	20.98	101.15	5.	-14.	44.					1.	1.	.063			.365
131.48	204.59	241.33	357.45	20.49	102.64	5.	-14.	44.					1.	1.	.063			.363
131.45	204.76	240.84	357.61	19.99	104.13	5.	-14.	44.					1.	1.	.063			.361
131.42	204.93	240.35	357.77	19.50	105.62	5.	-14.	44.					1.	1.	.063			.359
131.38	205.10	239.86	357.93	19.01	107.11	5.	-14.	44.					1.	1.	.063			.357
131.35	205.27	239.37	358.09	18.52	108.60	5.	-14.	44.					1.	1.	.063			.355
131.32	205.44	238.88	358.25	18.03	110.09	5.	-14.	44.					1.	1.	.063			.353
131.29	205.61	238.39	358.41	17.54	111.58	5.	-14.	44.					1.	1.	.063			.351
131.26	205.78	237.90	358.57	17.05	113.07	5.	-14.	44.					1.	1.	.063			.349
131.23	205.95	237.41	358.73	16.56	114.56	5.	-14.	44.					1.	1.	.063			.347
131.20	206.12	236.92	358.89	16.07	116.05	5.	-14.	44.					1.	1.	.063			.345
131.17	206.29	236.43	359.05	15.58	117.54	5.	-14.	44.					1.	1.	.063			.343
131.14	206.46	235.94	359.21	15.09	119.03	5.	-14.	44.					1.	1.	.063			.341
131.11	206.63	235.45	359.37	14.60	120.52	5.	-14.	44.					1.	1.	.063			.339
131.08	206.80	234.96	359.53	14.11	122.01	5.	-14.	44.					1.	1.	.063			.337
131.05	206.97	234.47	359.69	13.62	123.50	5.	-14.	44.					1.	1.	.063			.335
131.02	207.14	233.98	359.85	13.13	124.99	5.	-14.	44.					1.	1.	.063			.333
130.99	207.31	233.49	360.01	12.64	126.48	5.	-14.	44.					1.	1.	.063			.331
130.96	207.48	233.00	360.17	12.15	127.97	5.	-14.	44.					1.	1.	.063			.329
130.93	207.65	232.51	360.33	11.66	129.46	5.	-14.	44.					1.	1.	.063			.327
130.90	207.82	232.02	360.49	11.17	130.95	5.	-14.	44.					1.	1.	.063			.325
130.87	207.99	231.53	360.65	10.68	132.44	5.	-14.	44.					1.	1.	.063			.323
130.84	208.16	231.04	360.81	10.19	133.93	5.	-14.	44.					1.	1.	.063			.321
130.81	208.33	230.55	360.97	9.70	135.42	5.	-14.	44.					1.	1.	.063			.319
130.78	208.50	230.06	361.13	9.21	136.91	5.	-14.	44.					1.	1.	.063			.317
130.75	208.67	229.57	361.29	8.72	138.40	5.	-14.	44.					1.	1.	.063			.315
130.72	208.84	229.08	361.45	8.23	139.89	5.	-14.	44.					1.	1.	.063			.313
130.69	209.01	228.59	361.61	7.74	141.38	5.	-14.	44.					1.	1.	.063			.311
130.66	209.18	228.10	361.77	7.25	142.87	5.	-14.	44.					1.	1.	.063			.309
130.63	209.35	227.61	361.93	6.76	144.36	5.	-14.	44.					1.	1.	.063			.307
130.60	209.52	227.12	362.09	6.27	145.85	5.	-14.	44.					1.	1.	.063			.305
130.57	209.69	226.63	362.25	5.78	147.34	5.	-14.	44.					1.	1.	.063			.303
130.54	209.86	226.14	362.41	5.29	148.83	5.	-14.	44.					1.	1.	.063			.301
130.51	209.93	225.65	362.57	4.80	150.32	5.	-14.	44.					1.	1.	.063			.299
130.48	210.10	225.16	362.73	4.31	151.81	5.	-14.	44.					1.	1.	.063			.297
130.45	210.27	224.67	362.89	3.82	153.30	5.	-14.	44.					1.	1.	.063			.295
130.42	210.44	224.18	363.05	3.33	154.79	5.	-14.	44.					1.	1.	.063			.293
130.39	210.61	223.69	363.21	2.84	156.28	5.	-14.	44.					1.	1.	.063			.291
130.36	210.78	223.20	363.37	2.35	157.77	5.	-14.	44.					1.	1.	.063			.289
130.33	210.95	222.71	363.53	1.86	159.26	5.	-14.	44.					1.	1.	.063			.287
130.30	211.12	222.22	363.69	1.37	160.75	5.	-14.	44.					1.	1.	.063			.285
130.27	211.29	221.73	363.85	0.88	162.24	5.	-14.	44.					1.	1.	.063			.283
130.24	211.46	221.24	364.01	0.39	163.73	5.	-14.	44.					1.	1.	.063			.281
130.21	211.63	220.75	364.17	-0.10	165.22	5.	-14.	44.					1.	1.	.063			.279
130.18	211.80	220.26	364.33	-0.61	166.71	5.	-14.	44.					1.	1.	.063			.277
130.15	211.97	219.77	364.49	-1.12	168.20	5.	-14.	44.					1.	1.	.063			.275
130.12	212.14	219.28	364.65	-1.63	169.69	5.	-14.	44.					1.	1.	.063			.273
130.09	212.31	218.79	364.81	-2.14	171.18	5.	-14.	44.					1.	1.	.063			.271
130.06	212.48	218.30	364.97	-2.65	172.67	5.	-14.	44.					1.	1.	.063			.269
130.03	212.65	217.81	365.13	-3.16	174.16	5.	-14.	44.					1.	1.	.063			.267
130.00	212.82	217.32	365.29	-3.67	175.65	5.	-14.	44.					1.	1.	.063			.265
129.97	212.99	216.83	365.45	-4.18	177.14	5.	-14.	44.					1.	1.	.063			.263
129.94	213.16	216.34	365.61	-4.69	178.63	5.	-14.	44.					1.	1.	.063			.261
129.91	213.33	215.85	365.77	-5.20	180.12	5.	-14.	44.					1.	1.	.063			.259
129.88	213.50	215.36	365.93	-5.71	181.61	5.	-14.	44.					1.	1.	.063			.257
129.85	213.67	214.87	366.09	-6.22	183.10	5.	-14.	44.					1.	1.	.063			.255
129.82	213.84	214.38	366.25	-6.73	184.59	5.	-14.	44.					1.	1.	.063			

Computer program CLOCK3 (cont)

139.13	209.43	253.66	317.39	5.83	65.39	-16.	48.	1.	1.	1.	.065	.423
139.14	209.61	253.12	317.57	5.29	67.02	-16.	48.	1.	1.	1.	1.	.423
139.15	209.79	252.57	317.74	4.74	68.64	5.	-16.	48.	1.	1.	1.	.430
139.16	209.96	252.03	317.92	4.20	70.26	5.	-16.	48.	1.	1.	1.	.434
139.17	210.14	251.49	319.10	3.65	71.88	5.	-16.	48.	1.	1.	1.	.437
139.18	210.32	250.94	318.27	3.11	73.50	5.	-16.	48.	1.	1.	1.	.431
139.19	210.47	250.40	318.45	2.56	75.11	5.	-16.	48.	1.	1.	1.	.427
139.20	210.67	249.85	318.63	2.02	76.73	5.	-16.	48.	1.	1.	1.	.422
139.21	210.85	249.31	318.80	1.48	78.34	5.	-16.	46.	1.	1.	1.	.418
139.22	211.02	248.77	318.98	1.94	79.96	5.	-16.	48.	1.	1.	1.	.413
139.23	211.20	248.23	319.16	.40	81.58	5.	-16.	48.	1.	1.	1.	.409
139.24	211.38	247.69	319.33	359.86	83.19	5.	-16.	48.	1.	1.	1.	.405
139.25	211.55	247.16	319.51	359.32	84.82	5.	-16.	48.	1.	1.	1.	.400
139.26	211.73	246.62	319.68	358.79	86.45	5.	-16.	48.	1.	1.	1.	.396
139.27	211.91	246.09	319.86	358.25	88.09	5.	-16.	46.	1.	1.	1.	.393
139.28	212.08	245.55	320.04	357.72	89.73	5.	-16.	48.	1.	1.	1.	.389
139.29	212.26	245.02	320.21	357.19	91.37	5.	-16.	48.	1.	1.	1.	.386
139.30	212.44	244.50	320.39	356.66	92.99	5.	-16.	48.	1.	1.	1.	.383
139.31	212.61	243.97	320.57	356.14	94.60	5.	-15.	47.	1.	1.	1.	.380
139.32	212.79	243.45	320.74	355.61	96.20	5.	-15.	47.	1.	1.	1.	.377
139.33	212.97	242.93	320.92	355.09	97.77	5.	-15.	46.	1.	1.	1.	.373
139.34	213.14	242.41	321.10	354.58	99.31	5.	-15.	45.	1.	1.	1.	.374
139.35	213.32	241.89	321.27	354.06	100.83	5.	-15.	44.	1.	1.	1.	.371
139.36	213.50	241.38	321.45	353.55	102.31	5.	-15.	43.	1.	1.	1.	.368
139.37	213.68	240.86	321.63	353.04	63.75	5.	-15.	45.	1.	1.	1.	.363
139.38	213.85	240.35	321.80	352.53	65.27	5.	-15.	45.	1.	1.	1.	.402
139.39	214.02	239.84	321.98	352.03	66.77	5.	-15.	44.	1.	1.	1.	.406
139.40	214.20	239.32	322.15	351.53	68.26	5.	-15.	44.	1.	1.	1.	.410
139.41	200.91	232.70	322.33	31.41	68.27	5.	-16.	47.	1.	1.	1.	.413
139.42	201.09	232.17	322.51	30.87	69.85	5.	-16.	47.	1.	1.	1.	.455
139.43	201.27	231.64	322.69	30.34	71.43	5.	-16.	47.	1.	1.	1.	.462
139.44	201.45	231.12	322.87	29.81	73.01	5.	-16.	47.	1.	1.	1.	.469
139.45	201.62	230.60	323.04	29.28	74.58	5.	-16.	46.	1.	1.	1.	.475
139.46	201.80	230.08	323.21	28.75	76.15	5.	-16.	46.	1.	1.	1.	.473
139.47	201.97	229.56	323.39	28.22	77.73	5.	-16.	47.	1.	1.	1.	.470
139.48	202.15	229.04	323.57	27.70	79.31	5.	-16.	47.	1.	1.	1.	.467
139.49	202.33	228.46	323.75	27.17	80.88	5.	-16.	47.	1.	1.	1.	.464
139.50	202.50	227.94	323.92	26.64	82.46	5.	-16.	47.	1.	1.	1.	.461
139.51	202.68	227.41	324.10	26.12	84.04	5.	-16.	47.	1.	1.	1.	.458
139.52	202.86	226.89	324.28	25.59	85.64	5.	-16.	47.	1.	1.	1.	.455
139.53	203.03	226.36	324.45	25.07	87.26	5.	-16.	48.	1.	1.	1.	.452
139.54	203.21	225.83	324.63	24.54	88.87	5.	-16.	48.	1.	1.	1.	.449
139.55	203.39	225.31	324.81	24.01	90.49	5.	-16.	48.	1.	1.	1.	.446
139.56	203.56	224.78	324.98	23.49	92.11	5.	-16.	48.	1.	1.	1.	.443
139.57	203.74	224.26	325.16	22.96	93.73	5.	-16.	48.	1.	1.	1.	.440
139.58	203.92	223.73	325.34	22.44	95.34	5.	-16.	47.	1.	1.	1.	.437
139.59	204.10	223.21	325.52	21.91	96.93	5.	-16.	47.	1.	1.	1.	.434
139.60	204.28	222.68	325.70	21.38	98.51	5.	-16.	46.	1.	1.	1.	.431
139.61	204.45	222.15	325.87	20.85	100.07	5.	-16.	46.	1.	1.	1.	.428
139.62	204.63	221.63	326.05	20.33	101.61	5.	-16.	45.	1.	1.	1.	.425
139.63	204.80	221.10	326.22	19.80	103.12	5.	-16.	44.	1.	1.	1.	.422
139.64	204.98	220.58	326.40	19.28	63.75	5.	-16.	47.	1.	1.	1.	.460
139.65	205.16	220.05	326.58	18.75	65.34	5.	-16.	47.	1.	1.	1.	.464
139.66	205.34	219.53	326.76	18.22	66.92	5.	-16.	47.	1.	1.	1.	.466
139.67	205.52	219.00	326.93	17.69	68.49	5.	-16.	47.	1.	1.	1.	.469
139.68	205.70	218.48	327.11	17.16	70.07	5.	-16.	46.	1.	1.	1.	.471
139.69	205.88	217.95	327.29	16.63	71.64	5.	-16.	46.	1.	1.	1.	.474
139.70	206.06	217.42	327.47	16.10	73.22	5.	-16.	47.	1.	1.	1.	.476
139.71	206.24	216.89	327.64	15.57	74.79	5.	-16.	47.	1.	1.	1.	.470
139.72	206.42	216.36	327.82	15.04	76.38	5.	-16.	47.	1.	1.	1.	.464
139.73	206.60	215.83	328.00	14.51	77.96	5.	-16.	47.	1.	1.	1.	.458

Computer program CLOCK3 (cont)

[illegible]

Computer program FLOCI3 (cont)

[illegible]

132.94	201.98	251.55	350.21	28.22	71.67	5-	-16-	46-	-1-	1-	1-	.082	.410
132.90	202.15	251.53	350.38	27.69	73.24	5-	-16-	46-	-1-	1-	1-	.082	.415
132.87	202.33	250.50	350.55	27.17	74.79	5-	-15-	46-	-1-	1-	1-	.082	.413
132.83	202.50	249.98	350.74	26.64	76.35	5-	-15-	45-	-1-	1-	1-	.082	.410
132.80	202.68	249.46	350.91	26.12	77.91	5-	-15-	46-	-1-	1-	1-	.082	.408
132.77	202.85	248.91	351.09	25.60	79.47	5-	-15-	46-	-1-	1-	1-	.082	.406
132.73	203.03	248.42	351.26	25.08	81.02	5-	-15-	46-	-1-	1-	1-	.082	.403
132.70	203.20	247.90	351.44	24.55	82.58	5-	-15-	46-	-1-	1-	1-	.081	.401
132.66	203.38	247.38	351.61	24.04	84.13	5-	-15-	46-	-1-	1-	1-	.081	.398
132.63	203.55	246.86	351.79	23.53	85.71	5-	-15-	47-	-1-	1-	1-	.081	.396
132.60	203.73	246.35	351.96	23.01	87.29	5-	-15-	47-	-1-	1-	1-	.081	.394
132.57	203.90	245.83	352.13	22.50	88.87	5-	-15-	47-	-1-	1-	1-	.081	.391
132.54	204.08	245.31	352.30	22.00	90.45	5-	-15-	47-	-1-	1-	1-	.081	.389
132.51	204.25	244.79	352.47	21.50	92.03	5-	-15-	47-	-1-	1-	1-	.081	.387
132.48	204.43	244.27	352.64	21.00	93.61	5-	-15-	47-	-1-	1-	1-	.081	.385
132.45	204.60	243.75	352.81	20.50	95.19	5-	-15-	47-	-1-	1-	1-	.081	.383
132.42	204.78	243.23	352.98	20.00	96.77	5-	-15-	47-	-1-	1-	1-	.081	.381
132.39	204.95	242.71	353.15	19.50	98.35	5-	-15-	47-	-1-	1-	1-	.081	.379
132.36	205.13	242.19	353.32	19.00	99.93	5-	-15-	47-	-1-	1-	1-	.081	.377
132.33	205.30	241.67	353.49	18.50	101.51	5-	-15-	47-	-1-	1-	1-	.081	.375
132.30	205.48	241.15	353.66	18.00	103.09	5-	-15-	47-	-1-	1-	1-	.081	.373
132.27	205.65	240.63	353.83	17.50	104.67	5-	-15-	47-	-1-	1-	1-	.081	.371
132.24	205.83	240.11	354.00	17.00	106.25	5-	-15-	47-	-1-	1-	1-	.081	.369
132.21	206.00	239.59	354.17	16.50	107.83	5-	-15-	47-	-1-	1-	1-	.081	.367
132.18	206.18	239.07	354.34	16.00	109.41	5-	-15-	47-	-1-	1-	1-	.081	.365
132.15	206.35	238.55	354.51	15.50	110.99	5-	-15-	47-	-1-	1-	1-	.081	.363
132.12	206.53	238.03	354.68	15.00	112.57	5-	-15-	47-	-1-	1-	1-	.081	.361
132.09	206.70	237.51	354.85	14.50	114.15	5-	-15-	47-	-1-	1-	1-	.081	.359
132.06	206.88	236.99	355.02	14.00	115.73	5-	-15-	47-	-1-	1-	1-	.081	.357
132.03	207.05	236.47	355.19	13.50	117.31	5-	-15-	47-	-1-	1-	1-	.081	.355
132.00	207.23	235.95	355.36	13.00	118.89	5-	-15-	47-	-1-	1-	1-	.081	.353
131.97	207.40	235.43	355.53	12.50	120.47	5-	-15-	47-	-1-	1-	1-	.081	.351
131.94	207.58	234.91	355.70	12.00	122.05	5-	-15-	47-	-1-	1-	1-	.081	.349
131.91													

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REFERENCE

- D-1 G.G. Lowen, City College of N.Y., and F.R. Tepper, ARRADCOM, "Fuze Gear Train Analysis," Technical Report ARLCD-TR-79030, ARRADCOM, Dover, NJ, December 1979.

APPENDIX E
COMPUTER PROGRAM CLOCK4 (REVISED)

The original program descriptions were given in appendix I of Fuze Gear Train Analysis (ref E-1). The following appendix contains revised descriptions, listings and sample outputs of computer program CLOCK4, which computes point and cycle efficiencies for two pass clock gear trains in a spin environment.

The following changes were made:

1. The diametral pitches of both meshes are given as data and printed in the output.

2. The initialization parameters J (one for each of the two meshes) are introduced. They are given as part of the data and are printed in the output. Again, these parameters allow the arbitrary choice of the initial point of contact anywhere within the possible range of contact points.

The kinematics of computer program CLOCK4 is again based on the work in appendix G (ref E-1). The moment input-output relationships are derived in appendix H (ref E-1). This program is in many ways very similar to computer program CLOCK3 with the exception that only two meshes are involved, and therefore, whenever possible, reference will be made to computer program CLOCK3. Again, it is assumed that the two meshes will have been tested by computer program CLOCK1 for their geometric suitability. The format of the following is identical to that used in appendix D.

Input Parameters

The following parameters represent the input data for the program (appendix D):

PSUBD1, PSUBD2

MU

RPM

CAPRP1, CAPRP2, RP2, RP3

RHOG1, RHOG2, RHOP1, RHOP2

ACG1, ACG2, ACP1, ACP2

R1, R2, R3

TG1, TG2, TP1, TP2

NG1, NG2, NP2, NP3

RHO1, RHO2, RHO3

M1, M2, M3

MD

K

J1, J2

The angular velocity of the input gear is incorporated into the program as PHDOT1 = -1. All velocity computations are based on this model. The input motion in the fuse gearing model is negative (fig. A-10, ref E-1).

Computations

Computations of Gear Tooth Parameters

The required computations are identical to those for the revised computer program CLOCK3 in appendix D, with the exception that only two meshes are considered.

Computation of MIN, GAMMAS and BETAS

The input moment is computed in the manner of equation D-1 of appendix D. In addition, the angles γ_2 , γ_3 , β_1 and β_2 are found according to the expressions given in appendix A (ref E-1).

Computations of Other Parameters

The computations of the angles $\Delta\phi_1$ and $\Delta\psi_1$, the length L_1 as well as the centrifugal forces Q_1 , Q_2 and Q_3 (called Q_{3p} by equation H-245, ref E-1) are identical to those described in the parallel section dealing with computer program CLOCK3 in appendix D.

Preliminary Computations for Mesh 1

The preliminary computations for mesh 1 are similar to those discussed in appendix D.

Preliminary Computations for Mesh 2

The preliminary computations for mesh 2 are similar to those discussed in appendix D.

Gear Train Motion Model: Initial Contact Angles, Kinematics, Point and Cycle Efficiencies

The simulation of the gear train model, which is necessary for the determination of both POINTEF and CYCLEFF, is found in a loop starting with statement label no. 20 and ending with card no. 542. The motions of the individual driving gears are initialized at the angles PH11 and PH12, respectively, with the help of the initialization parameters J_1 ($i=1,2$) according to equation D-17 (app D).

The additional parameter J_3 is set equal to zero to mark the first cycle of computations (statement no. 318). J_3 becomes equal to unity for all subsequent computations (see statement no. 541).

The parameter J_4 is used to distinguish between the two possible contact conditions of mesh no. 1. $J_4 = 0$ whenever the first set of teeth is in contact. $J_4 = 1$ once the latest possible value of ϕ_1 has been reached, and contact must be transferred to the second set of teeth in order to obtain a complete cycle of motion for this mesh. $J_4 = 0$ at all times if $J_1 = 0$, i.e., contact is made in mesh no. 1 at the earliest possible point.

Both meshes will be in round on round contact until either reaches its respective transition angle PH11T or PH12T. Once the transition angles are past, the meshes will be in round on flat contact. These regimes continue until the final angles PH11F and PH12F are reached.

The increment DDPH11 of the input gear 1 is obtained from an adaptation of equations A-207 and A-208 (ref E-1), in which tooth numbers, rather than base circle radii are used. The increment DDPH12 of gear 2 is related to the increment of the pinion angle PS11.

While the motion of gear 1 is terminated when the angle PH11 reaches one increment before the starting angle, gear 2 must be reset to its earliest possible angle PH12I whenever its latest angle PH12F has been reached.*

★

If $J_1 = 0$, the computation is terminated for $PH11 < PH11F + DDPH11$. If $J_1 \neq 0$, and therefore $J_4 = 1$, computation is terminated when $PH11 < PH11A + DDPH11$. In the above, PH11A represents the starting angle of mesh 1 in the manner of equation D-17. (Card no. 316).

The appropriate choice of moment equation depends upon which of the four possible combinations of contact conditions, as indicated by table H-2 (ref E-1), is applicable.

The following discusses the kinematics of the individual meshes as well as the determination of the point and cycle efficiencies where they differ from the description in appendix D.

Kinematics. The program only utilizes the kinematics of meshes 1 and 2. These are identical with those for the revised computer program CLOCK3, as given in appendix D.

Moment Computations, Point and Cycle Efficiencies. Regardless of the combination of contact conditions, the point efficiency is computed according to equation 3 (ref E-1), i.e.,

$$\epsilon_p = \text{POINTEF} = K_{\text{RATIO}} \frac{M_{o31}}{M_{in}} \quad (\text{E-1})$$

where, with $\dot{\phi}_1 = -1$

$$K_{\text{RATIO}} = \left| \dot{\psi}_2 \right| \quad (\text{E-2})$$

The cycle efficiency determination is based on equation I-21 through I-23 (ref E-1).

The moment computations begin with the statement label no. 24, and initially consist of the determination of selected variables between A11 and A72 and selected variables between C6 and C36, as applicable to the analyses of appendix H (ref E-1). The governing contact combination (table H-2, ref E-1) is determined with the help of the four moment control statements, which start with card no. 508. Once the appropriate combination is established, the program is directed to one of the four associated moment expressions. These expressions for M_{o31} coincide with those given by equation H-260, H-261, H-277 and H-278 (ref E-1). They are listed in the above order beginning with statement label no. 25 and ending with statement label no. 28.

The rationale of the control statements for meshes 1 and 2 is identical to that given for revised computer program CLOCK3 (appendix D).

Output

The output of the program is best explained with the help of the sample problem at the end of the program.

Input Parameters (see fourth and fifth sets of gear data of appendix C)

Mesh 1

CAPRP1	= R_{p1}	= 0.55000 in. (1.397 cm)	PSUBD1	= P_{d1}	= 50
RP2	= r_{p2}	= 0.08000 in. (0.2032 cm)	J1	=	0.90
ACG1	= a_{G1}	= 0.54656 in. (1.3883 cm)			
ACP1	= a_{p1}	= 0.07998 in. (0.2031 cm)			
RHOG1	= ρ_{G1}	= 0.04322 in. (0.1098 cm)			
RHOP1	= ρ_{p1}	= 0.01400 in. (0.0356 cm)			
TG1	= t_{G1}	= 0.03175 in. (0.0806 cm)			
TP1	= t_{p1}	= 0.02096 in. (0.0532 cm)			
NG1	= n_{G1}	= 55			
NP2	= n_{p2}	= 8			

Mesh 2

CAPRP2	= R_{p2}	= 0.39286 in. (0.9978 cm)	PSUBD2	= P_{d2}	= 70
RP3	= r_{p3}	= 0.05714 in. (0.1451 cm)	J2	=	0.90
ACG2	= a_{G2}	= 0.39040 in. (0.9916 cm)			
ACP2	= a_{p2}	= 0.05709 in. (0.1450 cm)			
RHOG2	= ρ_{G2}	= 0.03087 in. (0.0784 cm)			
RHOP2	= ρ_{p2}	= 0.01000 in. (0.0254 cm)			
TG2	= t_{G2}	= 0.02268 in. (0.0576 cm)			
TP2	= t_{p2}	= 0.01497 in. (0.0380 cm)			
NG2	= n_{G2}	= 55			
NP3	= n_{p3}	= 8			

In addition

MU = 0.2
 RPM = 1000
 M1 = m_1 = 0.12×10^{-3} lb-sec²/in. (2.101×10^{-2} kg)
 M2 = m_2 = 0.253×10^{-4} lb-sec²/in. (4.430×10^{-3} kg)
 M3 = m_3 = 0.153×10^{-5} lb-sec²/in. (2.679×10^{-4} kg)
 R1 = R_1 = 0.225 in. (0.572 cm)
 R2 = R_2 = 0.497 in. (1.2624 cm)
 R3 = R_3 = 0.640 in. (1.6256 cm)
 RHO1 = ρ_1 = 0.062 in. (0.157 cm)
 RHO2 = ρ_2 = 0.025 in. (0.064 cm)
 RHO3 = ρ_3 = 0.018 in. (0.041 cm)
 MD = md^2 = 0.275×10^{-5} lb-sec²-in. (3.105×10^{-7} kg-m²)
 K = 25

Computed Values

At the beginning of the output, one finds MIN = M_{in} . Subsequently, the following are listed for each mesh:

ϵ_{p1} , the length of the pinion flats
 β_1 , the fuze body pivot to pivot line angles
 ψ_{T1} and ϕ_{T1} , the transition angles
 ϕ_{I1} and ψ_{I1} , the earliest angles
 ϕ_{F1} and ψ_{F1} , the latest angles

Finally, for the full range of the input angles ϕ_1 , the point efficiency POINTEF is listed, in addition to other parameters which are useful for checking purposes. Note that DPSI1 and DPSI2 represent ψ_1 and ψ_2 , respectively. The cycle efficiency CYCLEFF is found at the end of the output.

1.63

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Computer program CLOCK4 (cont)

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PROGRAM CLOCK4 74/74 OPT=1

```

110      1G11)
        IF (G11-G1.FPI) GO TO 2
        PHIIT=PHI11
        PS11T=PS11T1
        GO TO 4
      2 CALL TRANS1 (RHOG1,ALPHP1,BETA1,FPI,ACG1,B1,DELG1,2,PS11T2,PHI11T2,
115      1G12)
        IF (G12-LT.FPI) GO TO 3
        WRITE (6,51)
        STOP
      3 PHIIT=PHI11T2
        PS11T=PS11T2
      4 IF (PHIIT-LT.0.) PHIIT=PHIIT+2.*PI
        IF (PS11T-LT.0.) PS11T=PS11T+2.*PI
        PHIITD=PHIIT/2
        PS11TD=PS11T/2
        WRITE (6,52) PHIITD,PS11TD
      C
      C      DETERMINATION OF CORRECT SIGN FOR ROUND ON FLAT REGIME OF MESH 1
      C
120      A1F=ACG1*CCS(PHIIT+DELG1+ALPHP1)-B1*CCS(BETA1+ALPHP1)
        B1F=-ACG1*SIN(PHIIT+DELG1+ALPHP1)+B1*SIN(BETA1+ALPHP1)
        C1F=RHOG1
        ROOT1F=A1F+A1F+B1F+B1F-C1F+C1F
        Y1F2=A1F+SORT(ROOT1F)
        X1F=B1F+C1F
        PS11F1=2.*ATAN2(Y1F1,X1F)
        PS11F2=2.*ATAN2(Y1F2,X1F)
        IF (PS11F1-LT.0.) PS11F1=PS11F1+2.*PI
        IF (PS11F2-LT.0.) PS11F2=PS11F2+2.*PI
        IF (ABS(PS11F1-PS11T)-LT.ABS(PS11F2-PS11T)) GO TO 5
        SIGN1F=-1.
        GO TO 6
      C
130      5 SIGN1F=1.
      C
      C      LATEST AND EARLIEST POSSIBLE VALUES OF PHI AND PSI FOR MESH 1
      C
140      DO 7 I=1,2600
        PHI1D=PHI1TD-(I-1.)/100.
        PHI1=PHI1D+Z
        A1F=ACG1*CCS(PHI1+DELG1+ALPHP1)-B1*CCS(BETA1+ALPHP1)
        B1F=-ACG1*SIN(PHI1+DELG1+ALPHP1)+B1*SIN(BETA1+ALPHP1)
        C1F=RHOG1
        ROOT1F=A1F+A1F+B1F+B1F-C1F+C1F
        Y1F=A1F+SIGN1F*SORT(ROOT1F)
        X1F=B1F+C1F
        PS11F=2.*ATAN2(Y1F,X1F)
        IF (PS11F-LT.0.) PS11F=PS11F+2.*PI
        LX1=-B1*CCS(BETA1)+ACP1*CCS(PS11F-DPS11+DELPI)-ACG1*CCS(PHI1+DPHI1+
145      1DELG1)
        LY1=B1*SIN(BETA1)+ACP1*SIN(PS11F-DPS11+DELPI)-ACG1*SIN(PHI1+DPHI1+
        1DELG1)
        A 107
        A 108
        A 109
        A 110
        A 111
        A 112
        A 113
        A 114
        A 115
        A 116
        A 117
        A 118
        A 119
        A 120
        A 121
        A 122
        A 123
        A 124
        A 125
        A 126
        A 127
        A 128
        A 129
        A 130
        A 131
        A 132
        A 133
        A 134
        A 135
        A 136
        A 137
        A 138
        A 139
        A 140
        A 141
        A 142
        A 143
        A 144
        A 145
        A 146
        A 147
        A 148
        A 149
        A 150
        A 151
        A 152
        A 153
        A 154
        A 155
        A 156
        A 157
        A 158
        A 159

```

Computer program CLOCK4 (cont)

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PROGRAM CLOCK4 74/74 OPT=1

```

160      LL1=SQRT(LX1*LY1+LY1*LY1)
      DELELT=LL1-L1
      IF (DELELT.LE.0.) GO TO 8
7 CONTINUE
8      PH11F=PH11
      PS11FF=PS11F
      PH11I=PH11F+DPH11
      PS11I=PS11FF-DPS11
      IF (PS11I.LT.0.) PS11I=PS11I+2.*PI
      PH11ID=PH11I/Z
      PS11ID=PS11I/Z
      PH11FD=PH11F/Z
      PS11FD=PS11F/Z
      WRITE (6,53) PH11ID,PS11ID,PH11FD,PS11FD
C
175      DETERMINATION OF CORRECT SIGN FOR ROUND ON ROUND REGIME OF MESH 1
C
C
      A1R=ACG1*SIN(PH11I+DELG1-DELP1)-B1*SIN(BETA1-DELP1)
      B1R=ACG1*CCS(PH11I+DELG1-DELP1)-B1*CCS(BETA1-DELP1)
      C1R=ACG1*ACG1+ACG1*ACG1+B1*B1-L1*L1-2.*ACG1*B1*CCS(PH11I+DELG1-BE
      ITA1))/((2.*ACG1)
      ROOT1R=A1R+A1R+B1R+C1R
      Y1R=A1R+SQRT(ROOT1R)
      Y1R2=A1R+SQRT(ROOT1R)
      X1R=B1R+C1R
      PS11R1=2.*ATAN2(Y1R,X1R)
      PS11R2=2.*ATAN2(Y1R2,X1R)
      IF (PS11R1.LT.0.) PS11R1=PS11R1+2.*PI
      IF (PS11R2.LT.0.) PS11R2=PS11R2+2.*PI
      IF (ABS(PS11I-PS11R1).LT.ABS(PS11I-PS11R2)) GO TO 9
      SIGN1R=-1.
      GO TO 10
9 SIGN1R=1.
C
C
195      PRELIMINARY COMPUTATIONS FOR MESH 2
C
C
C      DETERMINATION OF TRANSITION ANGLE OF MESH 2
C
10 A2I=-RHOG2*CCS(BETA2-ALPHP2)+FP2*SIN(BETA2-ALPHP2)
      B2I=RHOG2*SIN(BETA2-ALPHP2)+FP2*CCS(BETA2-ALPHP2)
      C2I=ACG2*ACG2-RHOG2*RHOG2-B2*B2-FP2*FP2)/((2.*B2)
      ROOT2I=A2I+A2I+B2I+C2I
      Y2I=A2I+SQRT(ROOT2I)
      Y2I2=A2I+SQRT(ROOT2I)
      X2I=B2I+C2I
      PS12I1=2.*ATAN2(Y2I,X2I)
      PS12I2=2.*ATAN2(Y2I2,X2I)
      PS12E1=PS12I1
      PS12E2=PS12I2
      IF (PS12I1.GT.PI) PS12E1=PS12E1-2.*PI
      IF (PS12I1.LT.PI) PS12E1=PS12E1+2.*PI
      IF (PS12I2.GT.PI) PS12E2=PS12E2-2.*PI
      IF (PS12I2.LT.PI) PS12E2=PS12E2+2.*PI

```

Computer program CLOCK4 (cont)

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PROGRAM CLOCK4 74/74 OPT=1

```

215 IF (PSI121-GE.0.) TEST1=ABS(PI-BETA2+PSI121+ALPHP2)/Z
    IF (PSI121-LT.0.) TEST1=ABS(PI+BETA2-(PSI121+2.*PI+ALPHP2))/Z
    IF (PSI122-GE.0.) TEST2=ABS(PI-BETA2+PSI122+ALPHP2)/Z
    IF (PSI122-LT.0.) TEST2=ABS(PI+BETA2-(PSI122+2.*PI+ALPHP2))/Z
    IF (PSI121-LT.0.) PSI121=PSI121+2.*PI
    IF (PSI122-LT.0.) PSI122=PSI122+2.*PI
    PSI121D=PSI121/Z
    PSI122D=PSI122/Z
    WRITE (6,33) PSI121D,TEST1
    WRITE (6,34) PSI122D,TEST2
    CALL TRANS2 (RHOG2,ALPHP2,BETA2,FP2,ACG2,B2,DELG2,Z,PSI121,PHI121,
1021)
220 IF (G21-GT.FP2) GO TO 11
    PHI121=PHI121
    PSI121=PSI121
    GO TO 13
225 11 CALL TRANS2 (RHOG2,ALPHP2,BETA2,FP2,ACG2,B2,DELG2,Z,PSI121,PHI121,
    1022)
    IF (G22-LT.FP2) GO TO 12
    WRITE (6,54)
    STOP
230 12 PHI121=PHI121
    PSI121=PSI121
    13 IF (PHI121-LT.0.) PHI121=PHI121+2.*PI
    IF (PSI121-LT.0.) PSI121=PSI121+2.*PI
    PHI121D=PHI121/Z
    PSI121D=PSI121/Z
    WRITE (6,55) PHI121D,PSI121D
240 C
    C
    C DETERMINATION OF CORRECT SIGN FOR ROUND ON FLAT REGIME OF MESH 2
    A2F=ACG2+COS(PHI121-DELG2-ALPHP2)-B2+COS(BETA2-ALPHP2)
    B2F=-ACG2+SIN(PHI121-DELG2-ALPHP2)+B2+SIN(BETA2-ALPHP2)
    C2F=-RHOG2
    ROOT2F=A2F+A2F+82F+82F-C2F+C2F
    Y2F=A2F+SQRT(ROOT2F)
    Y2F=B2F+SQRT(ROOT2F)
    X2F=B2F+C2F
    PSI121=2.*ATAN2(Y2F1,X2F)
    PSI122=2.*ATAN2(Y2F2,X2F)
    IF (PSI121-LT.0.) PSI121=PSI121+2.*PI
    IF (PSI122-LT.0.) PSI122=PSI122+2.*PI
    IF (ABS(PSI121-PSI121)-LT.ABS(PSI122-PSI122)) GO TO 14
    PSI121D=PSI121/Z
    PSI122D=PSI122/Z
    SIGN2F=-1.
    GO TO 15
    14 SIGN2F=1.
    15 DO 16 I=1,1000
        PHI121D=PHI121D+(I-1)/100.
255 C
    C
    C LATEST AND EARLIEST POSSIBLE VALUES OF PHI AND PSI FOR MESH 2
260 C
    C
    C
265 C

```

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Computer program CLOCK4 (cont)

PROGRAM	CLOCK4	74/74	OPT=1	FTN 4.6+420	07/31/79	08.11.05	PAGE	9
425	A11=ABS((1.+MU*WU+S2R)*COS(LAMDA2)-CU*(S2R-1.)*SIN(LAMDA2))/DN						A 425	
	A13=ABS((-COS(GAMMA2)-WU*SIN(GAMMA2))/DN)						A 426	
	A14=ABS((1.+MU*WU+S2R)*SIN(LAMDA2)-WU*(1.-S2R)*COS(LAMDA2))/DN						A 427	
	A15=ABS((WU*(1.-S1R)*COS(LAMDA1)-(1.+WU*WU-S1R)*SIN(LAMDA1))/DN)						A 428	
	A16=ABS((WU*COS(GAMMA2)-SIN(GAMMA2))/DN)						A 429	
430	A17=ABS((1.-WU*WU-S1R)*COS(LAMDA1)-WU*(1.+S1R)*SIN(LAMDA1))/DN						A 430	
	A18=ABS(1./DN)						A 431	
	A19=ABS((1.-WU*WU-S1R)*SIN(LAMDA1)+WU*(1.+S1R)*COS(LAMDA1))/DN						A 432	
	A20=ABS(WU/DN)						A 433	
435	A21=ABS((WU*(1.-S2R)*SIN(LAMDA2)+(1.+WU*WU-S2R)*COS(LAMDA2))/DN)						A 434	
	A22=ABS((1.-WU*WU-S1F)*SIN(PSI1-ALPHA1)-WU*(1.+S1F)*COS(PSI1-ALPHA1))						A 435	
	A23=ABS((WU*SIN(GAMMA2)+COS(GAMMA2))/DN)						A 436	
	A24=ABS((1.+WU*WU-S2R)*SIN(LAMDA2)-WU*(1.-S2R)*COS(LAMDA2))/DN						A 437	
	A25=ABS((-WU*(1.+S1F)*SIN(PSI1-ALPHA1)+(WU*WU-S1F-1.)*COS(PSI1-ALPHA1))/DN						A 438	
440	A26=ABS((-SIN(GAMMA2)+WU*COS(GAMMA2))/DN)						A 439	
	A27=ABS((-SIN(GAMMA2)+S1F)*SIN(PSI1-ALPHA1)+WU*(S1F-1.)*COS(PSI1-ALPHA1))						A 440	
	A28=ABS(1./DN)						A 441	
	A29=ABS((WU*(S1F-1.)*SIN(PSI1-ALPHA1)+(1.+WU*WU-S1F)*COS(PSI1-ALPHA1))						A 442	
	A30=ABS(WU/DN)						A 443	
445	A31=ABS((1.+WU*WU+S2F)*SIN(PSI2+ALPHA2)-WU*(S2F-1.)*COS(PSI2+ALPHA2))						A 444	
	A32=ABS((WU*SIN(GAMMA2)+COS(GAMMA2))/DN)						A 445	
	A33=ABS((WU*(S2F-1.)*SIN(PSI2+ALPHA2)-WU*(1.+WU*WU-S2F)*COS(PSI2+ALPHA2))						A 446	
	A34=ABS((1.-WU*WU-S1F)*SIN(PSI1-ALPHA1)-WU*(1.+S1F)*COS(PSI1-ALPHA1))						A 447	
450	A35=ABS((1.-WU*WU-S1F)*SIN(PSI1-ALPHA1)-WU*(1.+S1F)*COS(PSI1-ALPHA1))						A 448	
	A36=ABS((WU*SIN(GAMMA2)+COS(GAMMA2))/DN)						A 449	
	A37=ABS((WU*(S2F-1.)*SIN(PSI2+ALPHA2)-WU*(1.+WU*WU-S2F)*COS(PSI2+ALPHA2))						A 450	
	A38=ABS((1.-WU*WU-S1F)*SIN(PSI1-ALPHA1)-WU*(1.+S1F)*COS(PSI1-ALPHA1))						A 451	
	A39=ABS((WU*SIN(GAMMA2)+COS(GAMMA2))/DN)						A 452	
	A40=ABS((WU*(S2F-1.)*SIN(PSI2+ALPHA2)-WU*(1.+WU*WU-S2F)*COS(PSI2+ALPHA2))						A 453	
455	A41=ABS((-WU*(1.+S1F)*SIN(PSI1-ALPHA1)+(WU*WU-S1F-1.)*COS(PSI1-ALPHA1))						A 454	
	A42=ABS((WU*COS(GAMMA2)-SIN(GAMMA2))/DN)						A 455	
	A43=ABS((1.+WU*WU+S2F)*SIN(PSI2+ALPHA2)-WU*(S2F-1.)*COS(PSI2+ALPHA2))						A 456	
	A44=ABS((1.-WU*WU-S1F)*SIN(PSI1-ALPHA1)-WU*(1.+S1F)*COS(PSI1-ALPHA1))						A 457	
	A45=ABS((WU*SIN(GAMMA2)+COS(GAMMA2))/DN)						A 458	
460	A46=ABS((WU*(S2F-1.)*SIN(PSI2+ALPHA2)-WU*(1.+WU*WU-S2F)*COS(PSI2+ALPHA2))						A 459	
	A47=ABS((1.-WU*WU-S1R)*SIN(LAMDA1)-WU*(1.+S1R)*COS(LAMDA1))/DN						A 460	
	A48=ABS((-SIN(GAMMA2)+WU*COS(GAMMA2))/DN)						A 461	
	A49=ABS((WU*(S2F-1.)*SIN(PSI2+ALPHA2)-WU*(1.+WU*WU-S2F)*COS(PSI2+ALPHA2))						A 462	
	A50=ABS((1.-WU*WU-S1R)*SIN(LAMDA1)-WU*(1.+S1R)*COS(LAMDA1))/DN						A 463	
465	A51=ABS((-SIN(GAMMA2)+WU*COS(GAMMA2))/DN)						A 464	
	A52=ABS((WU*(S2F-1.)*SIN(PSI2+ALPHA2)-WU*(1.+WU*WU-S2F)*COS(PSI2+ALPHA2))						A 465	
	A53=ABS((WU*(S2F-1.)*SIN(PSI2+ALPHA2)-WU*(1.+WU*WU-S2F)*COS(PSI2+ALPHA2))						A 466	
	A54=ABS((WU*(S2F-1.)*SIN(PSI2+ALPHA2)-WU*(1.+WU*WU-S2F)*COS(PSI2+ALPHA2))						A 467	
	A55=ABS((WU*(S2F-1.)*SIN(PSI2+ALPHA2)-WU*(1.+WU*WU-S2F)*COS(PSI2+ALPHA2))						A 468	
470	A56=ABS((WU*(S2F-1.)*SIN(PSI2+ALPHA2)-WU*(1.+WU*WU-S2F)*COS(PSI2+ALPHA2))						A 469	
	A57=ABS((WU*(S2F-1.)*SIN(PSI2+ALPHA2)-WU*(1.+WU*WU-S2F)*COS(PSI2+ALPHA2))						A 470	
	A58=ABS((WU*(S2F-1.)*SIN(PSI2+ALPHA2)-WU*(1.+WU*WU-S2F)*COS(PSI2+ALPHA2))						A 471	
	A59=ABS((WU*(S2F-1.)*SIN(PSI2+ALPHA2)-WU*(1.+WU*WU-S2F)*COS(PSI2+ALPHA2))						A 472	
	A60=ABS((WU*(S2F-1.)*SIN(PSI2+ALPHA2)-WU*(1.+WU*WU-S2F)*COS(PSI2+ALPHA2))						A 473	
475	A61=ABS((-SIN(GAMMA2)+WU*COS(GAMMA2))/DN)						A 474	
	A62=ABS((WU*(S2F-1.)*SIN(PSI2+ALPHA2)-WU*(1.+WU*WU-S2F)*COS(PSI2+ALPHA2))						A 475	
	A63=ABS((WU*(S2F-1.)*SIN(PSI2+ALPHA2)-WU*(1.+WU*WU-S2F)*COS(PSI2+ALPHA2))						A 476	
	A64=ABS((WU*(S2F-1.)*SIN(PSI2+ALPHA2)-WU*(1.+WU*WU-S2F)*COS(PSI2+ALPHA2))						A 477	

Computer program CLOCK4 (cont)

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FTN 4.6+420

PROGRAM CLOCK4 74/74 OPT=1

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480 C7=RU-RHQ2*(A13+A16)
      C8=-/ACPI*(SIN(PSI1+DELPI-LAMDA1))-MU*S1R=COS(PSI1+DELPI-LAMDA1);+M
      10-RHQ2*(A12+A15)+MU*S1R=RHP1
      C9=RU-RHQ1*(A18+A20)
      10=RU-RHQ1*(A17+A19)+ACG1*(SIN(PSI1+DELGI-LAMDA1))-MU*S1R=COS(PSI1
      1+DELGI-LAMDA1))-MU*S1R=RHP1
      C11=ACG2*(SIN(PSI2+DELG2-LAMDA2))-MU*S2R=COS(PSI2+DELG2-LAMDA2))-MU
      1-RHQ2*(A21+A24)+RU-RHQ2*S2R
      C12=RU-RHQ2*(A23+A26)
      C13=GI-MU-RHQ2*(A27+A29)
      C14=RU-RHQ1*(A29+A30)
      C15=RU-RHQ1*(A27+A29)+MU*S1F=RHP1+ACG1*(MU*S1F*SIN(PSI1+DELGI-PSI
      1+ALPH1))-COS(PSI1+DELGI-PSI1+ALPH1))
      C16=-MU-RHQ2*(A37+A40)+ACG2*(COS(PSI2+DELG2-PSI2-ALPH2))+MU*S2F=SI
      1N(PSI2+DELG2-PSI2-ALPH2))-MU*S2F=RHP2
      C20=RU-RHQ2*(A39+A42)
      C21=-RU-RHQ2*(A38+A41)+G1
      C22=-MU-RHQ2*(A43+A46)+ACG2*(COS(PSI2+DELG2-PSI2-ALPH2))+MU*S2F=SI
      1N(PSI2+DELG2-PSI2-ALPH2))-MU*S2F=RHP2
      C23=RU-RHQ2*(A45+A48)
      C24=-RU-RHQ2*(A44+A47)+ACPI*(MU*S1R=COS(PSI1+DELPI-LAMDA1))-SIN(PSI
      1+DELPI-LAMDA1))-RU*S1R=RHP1
      C33=RU-RHQ3*(A66+A68)
      C34=RU-RHQ3*(A65+A67)-MU*S2R=RHP2+ACP2*(MU*S2R=COS(PSI2+DELPI-LAM
      1DA21-SINI(PSI2+DELPI-LAMDA2)))
      C35=RU-RHQ3*(A70+A72)
      C36=RU-RHQ3*(A69+A71)-G2
505 C
506 C
507 C
508 C
509 C
510 C
511 C
512 C
513 C
514 C
515 C
516 C
517 C
518 C
519 C
520 C
521 C
522 C
523 C
524 C
525 C
526 C
527 C
528 C
529 C
530 C
      POINT=ABS(PSOOT2)*MO3/MIN
      IF ((PSI1-GE.PHI11).AND.(PSI2-LE.PHI21)) GO TO 25
      IF ((PSI1-LE.PHI11).AND.(PSI2-LE.PHI21)) GO TO 26
      IF ((PSI1-LE.PHI11).AND.(PSI2-GE.PHI21)) GO TO 27
      IF ((PSI1-GE.PHI11).AND.(PSI2-GE.PHI21)) GO TO 28
      POINT EXPRESSIONS
25 MO31=MIN(C8+C34/(C6+C10))-Q1=C8+C9+C34/(C6+C10)-Q2=C7+C34/C6-Q3=C33
      MO3=Q3
      POINT=ABS(PSOOT2)*MO3/MIN
      WRITE (6,36) PHI1D,PSI1D,PSI1D,PSI1D,PSI1D,PSOOT1,PSOOT2,S1R,S2R,POINTEF
      GO TO 29
26 MO32=MIN(C13+C34/(C11+C15))-Q1=C13+C14+C34/(C11+C15)-Q2=C12+C34/C11
      1-Q3=C33
      MO3=Q3
      POINT=ABS(PSOOT2)*MO3/MIN
      WRITE (6,37) PHI1D,PSI1D,PSI1D,PSI1D,PSI1D,PSOOT1,PSOOT2,S2R,S1F,G1,PGIN
      1TEF
      GO TO 29
27 MO33=MIN(C21+C36/(C15+C19))-Q1=C14+C21+C36/(C15+C19)-Q2=C20+C36/C19
      1-Q3=C35
      MO3=Q3
      POINT=ABS(PSOOT2)*MO3/MIN

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Computer program CLOCK4 (cont)

PROGRAM	CLOCK4	74/74	OPT=1	FTN 4-6+420	07/31/79	08-11-05	PAGE	12
585	54 FORMAT (6X,30H)SOMETHING IS WRONG WITH MESH 2)							A 584
	55 FORMAT (6X,8HPHI2TD =,F8.4,3X,8HPSI2TD =,F8.4)							A 585
	56 FORMAT (6X,8HPHI2TD =,F8.4,3X,8HPSI2TD =,F8.4,3X,8HPHI2FD =,F8.4,3							A 586
	1X,8HPSI2FD =,F8.4//)							A 587
	57 FORMAT (1H0,5X,16HCYCLE EFFICIENCY =,F5.3)							A 588
	58 FORMAT (3F10.5)							A 589
590	59 FORMAT (6X,4HR1 =,F8.5,3X,4HR2 =,F8.5,3X,4HR3 =,F8.5/)							A 590
	60 FORMAT (6X,5HFP1 =,F8.5,3X,5HFP2 =,F8.5/)							A 591
	61 FORMAT (3E15.5)							A 592
	62 FORMAT (6X,4HR1 =,E15.5,3X,4HR2 =,E15.5,3X,4HR3 =,E15.5/)							A 593
	END							A 594-

Computer program CLOCK4 (cont)

SUBROUTINE TRANS1	74/74	OPT=1	FTN 4.6+420	07/31/79	08.11.05	PAGE	1
1			SUBROUTINE TRANS1 (RHOG,ALPHP,BETA,FP,ACG,B,DELG,Z,PSIT,PHIT,G)	B	1		
			PI=3.14159	B	2		
			ST=(-RHOG*COS(PSIT-ALPHP)+B*SIN(BETA)+FP*SIN(PSIT-ALPHP))/ACG	B	3		
			CT=(-RHOG*SIN(PSIT-ALPHP)+B*COS(BETA)+FP*COS(PSIT-ALPHP))/ACG	B	4		
5			PHIT=ATAN2(ST,CT)-DELG	B	5		
			PHINEXT=PHIT-.1*Z	B	6		
			AF=ACG*COS(PHINEXT+DELG+ALPHP)-B*COS(BETA+ALPHP)	B	7		
			BF=-ACG*SIN(PHINEXT+DELG+ALPHP)+B*SIN(BETA+ALPHP)	B	8		
			CF=RHOG	B	9		
10			ROOTF=AF+BF+CF	B	10		
			YF1=ZF+SORT(ROOTF)	B	11		
			YF2=AF-SORT(ROOTF)	B	12		
			XF=BF+CF	B	13		
			PSINEX1=2.*ATAN2(YF1,XF)	B	14		
15			PSINEX2=2.*ATAN2(YF2,XF)	B	15		
			IF (PSINEX1.LT.0.) PSINEX1=PSINEX1+2.*PI	B	16		
			IF (PSINEX2.LT.0.) PSINEX2=PSINEX2+2.*PI	B	17		
			IF (ABS(PSINEX1-PSIT)-LT.ABS(PSINEX2-PSIT)) GO TO 1	B	18		
			PSINEX1=PSINEX2	B	19		
20			GO TO 2	B	20		
			1 PSINEXT=PSINEX1	B	21		
			2 G=(ACG*SIN(PHINEXT+DELG)+RHOG*COS(PSINEXT-ALPHP)-B*SIN(BETA))/SIN(	B	22		
			B	23			
			RETURN	B	24		
25			END	B	25-		

Computer program CLOCK4 (cont)

SUBROUTINE TRANS2	74/74	OPT=1	FTN 4.6+420	07/31/79	08.11.05	PAGE	1
1			SUBROUTINE TRANS2 (RHOG,ALPHP,BETA,FP,ACG,S,DELG,Z,PSIT,PHIT,G)	C	1		
			PI=3.14159	C	2		
			ST=1-RHOG*COS(PSIT+ALPHP)+B*SIN(BETA)+FP*SIN(PSIT+ALPHP))/ACG	C	3		
			CT=1-RHOG*SIN(PSIT+ALPHP)+B*COS(BETA)+FP*COS(PSIT+ALPHP))/ACG	C	4		
			PHIT=ATAN2(ST,CT)+DELG	C	5		
5			PHINEXT=PHIT+.12Z	C	6		
			AF=ACG*COS(PHINEXT-DELG-ALPHP)+B*COS(BETA-ALPHP)	C	7		
			BF=ACG*SIN(PHINEXT-DELG-ALPHP)+B*SIN(BETA-ALPHP)	C	8		
			CF=-RHOG	C	9		
			ROOTF=AF+BF+CF	C	10		
10			YF1=AF+SQRT(ROOTF)	C	11		
			YF2=BF+CF	C	12		
			XF=BF+CF	C	13		
			PSINEX1=2.*ATAN2(YF1,XF)	C	14		
			PSINEX2=2.*ATAN2(YF2,XF)	C	15		
15			IF (PSINEX1.LT.0.) PSINEX1=PSINEX1+2.*PI	C	16		
			IF (PSINEX2.LT.0.) PSINEX2=PSINEX2+2.*PI	C	17		
			IF (ABS(PSINEX1-PSIT)-LT.ABS(PSINEX2-PSIT)) GO TO 1	C	18		
			PSINEX1=PSINEX2	C	19		
			GO TO 2	C	20		
20			1 PSINEX1=PSINEX1	C	21		
			2 G=(ACG*SIN(PHINEXT-DELG)-RHOG*COS(PSINEX1+ALPHP)-B*SIN(BETA))/SIN(	C	22		
			C	23			
			RETURN	C	24		
25			END	C	25		

Computer program CLOCK4 (cont)

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PSURD1 = 50. PSURD2 = 70.
MIN = .030157 MU = .200 RPM = 1000.
CAPRP1 = .55000 CAPRP2 = .39206
RP2 = .06000 RP3 = .05714
ACG1 = .54656 ACE2 = .39040 ACP1 = .07998 ACP2 = .05769
NG1 = 55. NG2 = 55. NP2 = 8. NP3 = 8.
R1 = .22500 R2 = .49700 R3 = .64000
RHOG1 = .64322 RHOG2 = .63087 RHOP1 = .01400 RHOP2 = .01000
TC1 = .03175 TC2 = .02268 TP1 = .02096 TP2 = .01497
W1 = .12000E-03 W2 = .25300E-04 W3 = .15300E-05
RHQ1 = .062 RHQ2 = .025 RHQ3 = .018
WD = .2750E-05
K = 25.0
PHOOT1 = -1.0
J1 = .90 J2 = .90

FP1 = .07875 FP2 = .05621
BETAID = 135.0146 BETA2D = 211.4684
PSI11D = 331.1623 TEST11 = 8.5908
PSI112D = 11.5011 TEST12 = 48.9297

PHI11D = 135.4134 PSI11D = 331.1623
PHI11D = 138.2188 PSI11D = 311.9198 PHI11D = 131.6734 PSI11D = 356.9198

PSI12D = 335.0370 TEST21 = 48.8749
PSI12D = 15.2351 TEST22 = 8.6765

PHI12D = 211.0816 PSI12D = 15.2351
PHI12D = 208.2761 PSI12D = 34.4878 PHI12D = 214.8216 PSI12D = 349.4878

PHI11 PHI12 PSI11 PSI12 DPSI1 DPSI2 S1R S2R S1F G1 S2F G2 PCINTEF
132.33 214.17 352.69 353.71 7. -44. 1. -.071 1. -.051 -.319
132.29 214.42 352.94 353.06 7. -43. 1. -.071 1. -.051 -.317
132.25 214.67 353.20 350.44 7. -42. 1. -.071 1. -.051 -.316
132.21 268.28 353.45 34.48 7. -45. -1. 1. -.071 -.350
132.18 208.53 353.70 32.78 7. -45. -1. 1. -.071 -.354
132.14 208.78 353.95 31.05 7. -45. -1. 1. -.071 -.357
132.10 209.02 354.20 29.35 7. -45. -1. 1. -.071 -.361
132.05 209.27 354.44 27.56 6. -44. -1. 1. -.071 -.364

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Computer program CLOCK4 (cont)

132.02	205.52	354.69	25.97	6.	-44.	-1.	1.	-071	-367
131.99	209.76	354.94	24.28	6.	-44.	-1.	1.	-071	-370
131.85	210.01	355.18	22.53	6.	-44.	-1.	1.	-071	-367
131.81	210.25	355.43	20.93	6.	-44.	-1.	1.	-071	-363
131.87	210.50	355.67	19.25	6.	-44.	-1.	1.	-071	-360
131.83	210.74	355.91	17.58	6.	-44.	-1.	1.	-071	-357
131.79	210.98	356.15	15.91	6.	-44.	-1.	1.	-071	-354
131.75	211.22	356.43	14.25	6.	-44.	-1.	1.	-071	-351
131.72	211.46	356.64	12.57	6.	-44.	-1.	1.	-071	-347
131.68	211.70	356.89	10.89	6.	-44.	-1.	1.	-072	-344
138.22	211.71	311.92	10.87	7.	-49.	-1.	1.	-072	-385
138.18	211.97	312.16	9.31	7.	-49.	-1.	1.	-072	-382
138.14	212.23	312.45	7.15	7.	-49.	-1.	1.	-072	-379
138.10	212.49	312.71	5.30	7.	-49.	-1.	1.	-072	-376
138.07	212.75	312.97	3.44	7.	-49.	-1.	1.	-072	-374
138.03	213.02	313.23	1.60	7.	-49.	-1.	1.	-072	-372
137.99	213.28	313.49	359.77	7.	-49.	-1.	1.	-072	-370
137.95	213.54	313.75	357.96	7.	-49.	-1.	1.	-072	-369
137.91	213.80	314.02	356.17	7.	-49.	-1.	1.	-072	-367
137.88	214.06	314.28	354.41	7.	-49.	-1.	1.	-072	-366
137.84	214.32	314.54	352.69	7.	-49.	-1.	1.	-072	-365
137.80	214.58	314.80	351.00	7.	-49.	-1.	1.	-072	-364
137.76	208.78	315.06	34.48	7.	-49.	-1.	1.	-072	-403
137.72	208.54	315.32	32.69	7.	-49.	-1.	1.	-072	-409
137.69	208.80	315.58	30.90	7.	-49.	-1.	1.	-072	-414
137.65	209.06	315.84	29.12	7.	-49.	-1.	1.	-072	-418
137.61	209.32	316.10	27.34	7.	-49.	-1.	1.	-072	-423
137.57	209.58	316.36	25.56	7.	-49.	-1.	1.	-072	-428
137.53	209.84	316.62	23.77	7.	-49.	-1.	1.	-072	-430
137.50	210.10	316.88	21.99	7.	-49.	-1.	1.	-072	-427
137.46	210.36	317.14	20.20	7.	-49.	-1.	1.	-072	-423
137.42	210.62	317.40	18.41	7.	-49.	-1.	1.	-072	-420
137.39	210.88	317.66	16.62	7.	-49.	-1.	1.	-072	-417
137.34	211.14	317.92	14.83	7.	-49.	-1.	1.	-072	-414
137.30	211.40	318.18	13.01	7.	-49.	-1.	1.	-072	-410
137.27	211.66	318.44	11.19	7.	-49.	-1.	1.	-072	-407
137.23	211.92	318.71	9.35	7.	-49.	-1.	1.	-072	-403
137.19	212.18	318.97	7.50	7.	-49.	-1.	1.	-072	-400
137.15	212.44	319.23	5.66	7.	-49.	-1.	1.	-072	-397
137.11	212.70	319.49	3.81	7.	-49.	-1.	1.	-072	-394
137.08	212.96	319.75	1.98	7.	-49.	-1.	1.	-072	-392
137.04	213.22	320.01	1.15	7.	-49.	-1.	1.	-072	-390
137.00	213.48	320.27	358.35	7.	-49.	-1.	1.	-072	-384
136.96	213.74	320.53	356.56	7.	-49.	-1.	1.	-072	-385
136.92	214.00	320.79	354.80	7.	-49.	-1.	1.	-072	-386
136.89	214.26	321.05	353.07	7.	-49.	-1.	1.	-072	-384
136.85	214.52	321.31	351.36	7.	-49.	-1.	1.	-072	-383
136.81	214.78	321.57	349.72	7.	-49.	-1.	1.	-072	-382
136.77	208.28	321.83	34.48	7.	-49.	-1.	1.	-072	-380
136.73	208.54	322.09	32.69	7.	-49.	-1.	1.	-072	-423
136.70	208.80	322.35	30.90	7.	-49.	-1.	1.	-072	-428
136.66	209.06	322.61	29.12	7.	-49.	-1.	1.	-072	-433
136.62	209.32	322.87	27.34	7.	-49.	-1.	1.	-072	-441
136.58	209.58	323.13	25.56	7.	-49.	-1.	1.	-072	-444
136.54	209.84	323.39	23.77	7.	-49.	-1.	1.	-072	-448
136.51	210.10	323.65	21.99	7.	-49.	-1.	1.	-072	-453
136.47	210.36	323.91	20.19	7.	-49.	-1.	1.	-072	-458
136.43	210.62	324.18	18.39	7.	-49.	-1.	1.	-072	-463
136.39	210.88	324.44	16.53	7.	-49.	-1.	1.	-072	-468
136.35	211.14	324.70	14.60	7.	-49.	-1.	1.	-072	-473
136.31	211.41	324.96	12.98	7.	-49.	-1.	1.	-072	-478

Computer program CLOCK4 (cont)

136.28	211.67	325.22	11.14	7.	-48.	-1.	1.	-055	.413
136.24	211.93	325.48	9.30	7.	-49.	-1.	1.	-054	.408
136.20	212.19	325.74	7.44	7.	-49.	-1.	1.	-053	.403
136.16	212.45	326.00	5.59	7.	-49.	-1.	1.	-053	.398
136.12	212.71	326.27	3.73	7.	-49.	-1.	1.	-052	.394
136.09	212.98	326.53	1.89	7.	-48.	-1.	1.	-052	.390
136.05	213.24	326.79	.05	7.	-48.	-1.	1.	-051	.387
136.01	213.50	327.05	358.24	7.	-47.	-1.	1.	-051	.383
135.97	213.76	327.31	356.44	7.	-47.	-1.	1.	-051	.380
135.93	214.02	327.58	354.67	7.	-46.	-1.	1.	-051	.377
135.90	214.28	327.84	352.93	7.	-45.	-1.	1.	-051	.375
135.86	214.55	328.10	351.23	7.	-44.	-1.	1.	-051	.372
135.82	214.81	328.36	349.57	7.	-43.	-1.	1.	-051	.369
135.78	208.28	328.62	34.48	7.	-47.	-1.	-1.		.409
135.74	208.54	328.89	32.68	7.	-47.	-1.	-1.		.413
135.71	208.80	329.15	30.88	7.	-47.	-1.	-1.		.417
135.67	209.06	329.41	29.08	7.	-47.	-1.	-1.		.420
135.63	209.33	329.67	27.28	7.	-47.	-1.	-1.		.423
135.59	209.59	329.94	25.49	7.	-47.	-1.	-1.		.426
135.55	209.85	330.20	23.69	7.	-47.	-1.	-1.		.429
135.51	210.11	330.46	21.89	7.	-47.	-1.	-1.		.431
135.48	210.38	330.73	20.08	7.	-47.	-1.	-1.		.416
135.44	210.64	330.99	18.27	7.	-48.	-1.	-1.		.411
135.40	210.90	331.25	16.47	7.	-48.	-1.	-1.		.407
135.36	211.17	331.51	14.66	7.	-48.	-1.	-1.		.401
135.32	211.43	331.78	12.82	7.	-49.	-1.	-1.		.396
135.28	211.69	332.04	10.96	7.	-49.	-1.	-1.		.390
135.25	211.96	332.31	9.09	7.	-49.	-1.	-1.		.385
135.21	212.22	332.57	7.21	7.	-49.	-1.	-1.		.380
135.17	212.49	332.84	5.33	7.	-49.	-1.	-1.		.375
135.13	212.75	333.10	3.44	7.	-49.	-1.	-1.		.371
135.10	213.02	333.37	1.57	7.	-49.	-1.	-1.		.367
135.06	213.29	333.63	359.70	7.	-49.	-1.	-1.		.363
135.02	213.55	333.90	357.86	7.	-48.	-1.	-1.		.36
134.98	213.82	334.17	356.02	7.	-48.	-1.	-1.		.357
134.94	214.09	334.44	354.23	7.	-48.	-1.	-1.		.354
134.91	214.36	334.70	352.47	7.	-45.	-1.	-1.		.351
134.87	214.62	334.97	350.74	7.	-45.	-1.	-1.		.348
134.83	208.28	335.24	34.48	7.	-49.	-1.	-1.		.385
134.79	208.54	335.51	32.64	7.	-48.	-1.	-1.		.388
134.75	208.81	335.78	30.80	7.	-48.	-1.	-1.		.391
134.72	209.08	336.05	28.96	7.	-48.	-1.	-1.		.394
134.68	209.35	336.31	27.12	7.	-48.	-1.	-1.		.397
134.64	209.62	336.58	25.28	7.	-48.	-1.	-1.		.400
134.60	209.89	336.85	23.43	7.	-48.	-1.	-1.		.398
134.56	210.16	337.12	21.58	7.	-49.	-1.	-1.		.394
134.52	210.43	337.39	19.73	7.	-49.	-1.	-1.		.389
134.48	210.70	337.65	17.87	7.	-49.	-1.	-1.		.384
134.45	210.97	337.93	16.01	7.	-49.	-1.	-1.		.379
134.4	211.24	338.20	14.15	7.	-49.	-1.	-1.		.374
134.37	211.51	338.47	12.26	7.	-50.	-1.	-1.		.369
134.33	211.78	338.74	10.36	7.	-50.	-1.	-1.		.364
134.30	212.05	339.01	8.45	7.	-50.	-1.	-1.		.360
134.26	212.32	339.28	6.53	7.	-50.	-1.	-1.		.355
134.22	212.59	339.55	4.61	7.	-50.	-1.	-1.		.351
134.18	212.86	339.82	2.70	7.	-50.	-1.	-1.		.347
134.14	213.13	340.09	.80	7.	-50.	-1.	-1.		.344
134.11	213.40	340.36	352.92	7.	-49.	-1.	-1.		.341
134.07	213.67	340.63	351.06	7.	-49.	-1.	-1.		.338
134.03	213.94	340.90	352.22	7.	-49.	-1.	-1.		.335
133.99	214.21	341.17	353.42	7.	-47.	-1.	-1.		.333

Computer program CLOCK4 (cont)

133.95	214.48	341.44	351.66	7.	-46.	1.	-074	1.	.051	.331
133.92	214.75	341.71	349.93	7.	-45.	1.	-074	1.	.051	.328
133.88	208.28	341.98	34.48	7.	-49.	-1.	-073			.364
133.84	208.55	342.25	32.63	7.	-49.	-1.	-073			.367
133.80	208.62	342.52	30.78	7.	-48.	-1.	-073			.371
133.76	209.08	342.79	28.94	7.	-48.	-1.	-073			.374
133.73	209.35	343.06	27.99	7.	-48.	-1.	-073			.377
133.69	209.72	343.33	25.25	7.	-48.	-1.	-073			.380
133.65	209.89	343.60	23.41	7.	-48.	1.	-073			.379
133.61	210.16	343.87	21.57	7.	-48.	1.	-073			.375
133.57	210.43	344.14	19.73	7.	-48.	1.	-073			.370
133.53	210.70	344.41	17.88	7.	-49.	1.	-073			.366
133.50	210.97	344.67	16.03	7.	-49.	1.	-073			.362
133.46	211.23	344.94	14.19	7.	-49.	1.	-073		.056	.358
133.42	211.50	345.21	12.32	7.	-49.	1.	-073		.055	.353
133.38	211.77	345.48	10.44	7.	-49.	1.	-072		.054	.349
133.34	212.03	345.74	8.55	7.	-50.	1.	-072		.054	.345
133.31	212.30	346.01	6.66	7.	-50.	1.	-072		.053	.341
133.27	212.57	346.27	4.77	7.	-49.	1.	-072		.053	.337
133.23	212.83	346.54	2.89	7.	-49.	1.	-072		.052	.334
133.19	213.10	346.81	1.02	7.	-49.	1.	-072		.052	.331
133.15	213.36	347.07	359.18	7.	-48.	1.	-072		.051	.328
133.12	213.63	347.34	357.35	7.	-48.	1.	-072		.051	.326
133.08	213.89	347.60	355.55	7.	-47.	1.	-072		.051	.324
133.04	214.16	347.86	353.79	7.	-46.	1.	-072		.051	.322
133.00	214.42	348.13	352.06	7.	-45.	1.	-072		.051	.320
132.96	214.68	348.39	350.37	7.	-44.	1.	-072		.051	.318
132.93	208.28	348.65	34.48	7.	-47.	-1.	-072		.051	.353
132.89	208.54	348.91	32.68	7.	-47.	-1.	-072			.356
132.85	208.80	349.17	30.89	7.	-47.	-1.	-072			.360
132.81	209.06	349.44	29.11	7.	-47.	-1.	-072			.363
132.77	209.32	349.70	27.33	7.	-47.	-1.	-072			.366
132.73	209.56	349.96	25.55	7.	-47.	-1.	-072			.369
132.70	209.84	350.21	23.78	7.	-47.	1.	-072			.370
132.66	210.10	350.47	22.00	7.	-47.	1.	-072			.366
132.62	210.36	350.73	20.23	7.	-47.	1.	-072			.363
132.58	210.61	350.99	18.46	7.	-46.	1.	-072			.359
132.54	210.87	351.24	16.69	7.	-46.	1.	-071			.356
132.51	211.13	351.50	14.93	7.	-47.	1.	-071		.056	.352
132.47	211.38	351.76	13.15	7.	-47.	1.	-071		.055	.348
132.43	211.64	352.01	11.37	7.	-47.	1.	-071		.055	.344
132.39	211.89	352.27	9.57	7.	-47.	1.	-071		.054	.341

CYCLE EFFICIENCY = .379

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City College of the City University of New York
Mechanical Engineering Department
ATTN: Dr. G. Lowen (10)
137 St. and Convent Avenue
New York, NY 10031