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by

J. M. Harris

J. S. Glasgow

and

A. Rudnick

Battelle Memorial Institute

Columbus Laboratories

505 King Avenue

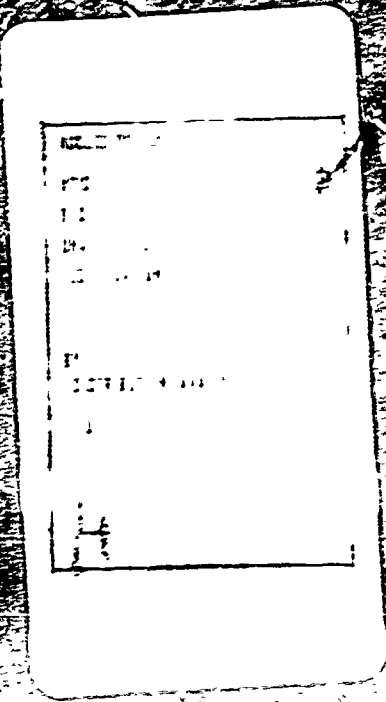Columbus, Ohio 43201

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13. ABSTRACT

Previous studies demonstrated that the currently used ballistic inspection of M-1 helmets could be replaced by an inspection based on thickness requirements. The objective of the current study was to identify the most effective way to perform the inspection in production situations, and to make a preliminary design of a thickness inspection system.

Several thickness-measuring methods were evaluated. Consideration was given to ultrasonics, electromechanical and pneumomechanical devices, radiological methods, and eddy current methods. Approaches based on both averaging and minimum seeking systems were considered. The evaluations were aided by brief engineering studies and by discussions with instrument manufacturers. The eight most promising systems were considered in some detail, and for these, schematic designs were developed. A comprehensive rating chart was used to aid in making a final selection. Factors considered in the selection process included potential accuracy, jig complexity, commercial availability of components, speed of operation, operator hazards, and overall reliability. Based on these considerations, a thickness-averaging ultrasonic system, containing a set of stationary transducers connected to averaging circuitry and digital readout, was selected as most appropriate. A design of such an inspection system was prepared.

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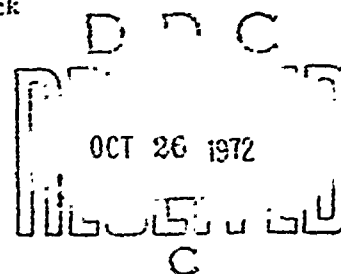DEVELOPMENT OF A NEW ACCEPTANCE

CRITERION FOR M-1 HELMETS

Phase II: Preliminary Design of a
Thickness Inspection System

by

J. M. Harris, J. S. Glasgow, and A. Rudnick

BATTELLE MEMORIAL INSTITUTE
Columbus Laboratories
505 King Avenue
Columbus, Ohio 43201

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ABSTRACT

Previous studies demonstrated that the currently used ballistic inspection of M-1 helmet could be replaced by an inspection based on thickness requirements. It was demonstrated that inspection based on thickness would provide greater confidence in the quality of helmets and do so at appreciably lower cost. The objective of the current study was to identify the most effective way to perform the inspection in production situations, and to make a preliminary design of a thickness inspection system.

Several thickness-measuring methods were evaluated. Consideration was given to ultrasonics, electromechanical and pneumomechanical devices, radiological methods, and eddy current methods. Approaches based on both averaging and minimum seeking systems were considered. The evaluations were aided by brief engineering studies and by discussions with instrument manufacturers. The eight most promising systems were considered in some detail, and for these, schematic designs were developed. A comprehensive rating chart was used to aid in making a final selection. Factors considered in the selection process included potential accuracy, jig complexity, commercial availability of components, speed of operation, operator hazards, and overall reliability. Based on these considerations, a thickness-averaging ultrasonic system, containing a set of stationary transducers connected to averaging circuitry and digital readout, was selected as most appropriate. A design of such an inspection system was prepared.

DEVELOPMENT OF A NEW ACCEPTANCE
CRITERION FOR M-1 HELMETS

Phase II: Preliminary Design of a
Thickness Inspection System

to

DEPARTMENT OF THE ARMY
U. S. Army Natick Laboratories

October, 1969

INTRODUCTION AND BACKGROUND

During the period from June, 1966, through July, 196/, the
U. S. Army Natick Laboratories sponsored at Battelle a study of the
influence of various parameters on the ballistic resistance of M-1
helmets*. The details and results of that study are contained in our
Summary Report, "A Study of Ballistic Protective, Chemical, and Physical
Properties of 200 M-1 Helmets and 200 Helmet Blanks", dated July 28,
1967. The broad objective of that program was to evaluate the potential
for replacing the current ballistic limit criterion for helmet accepta-
bility with a simpler, less expensive, and preferably nondestructive
method of inspection. It was the purpose of the current study to trans-
late the findings of the initial study into a preliminary design of a
usable inspection system.

Reviewing briefly, the initial study involved a detailed
investigation of 200 sets of helmets and helmet blanks; each helmet
and helmet blank set represented one heat-treatment lot. The following
data were obtained:

On each helmet blank -

o Ballistic limit (V_p50) for T-37, .22 Caliber fragment
   simulators.**

o Average thickness.

o Average hardness.

o Chemical composition.

o Tensile stress-strain properties in directions parallel
   and transverse to the rolling direction.

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* Contract No. DA19-129-AMC-1005 (N).

** The fragment simulators are described in Military Specification
   MIL-P-46593A, Projectile, Calibers .22, .30, .50 and 20 mm
   Fragment-simulating.

On each helmet –

o Thickness of each of 96 locations in the helmet.

o Hardness of each of 96 locations in the helmet.

o Metallographic analysis of the rim area of each helmet.

o Ballistic data as follows (T-37, .22 Cal. fragments
  simulators were used): On the average, 42 rounds were
  fired into each helmet. The data obtained were: location
  of point of impact, impact velocity, and a notation of
  whether or not the fragment simulator penetrated. These
  data were used to compute V_p50's for the entire helmet
  and for selected portions of the helmet.

In addition, deformation patterns in formed helmets were studied.

The data were analyzed to find relationships among the various
parameters. Particular emphasis was placed on finding relationships
between each of the parameters (including V_p50 of the blanks) and a
V_p50 of the helmet. In this regard, various V_p50's were calculated for
each helmet, viz., a V_p50 for the whole helmet, for the top part
(crown) alone, and for the bottom part alone. Also, ballistic data
from all 200 helmets were combined to allow computation of a V_p50 for
each of 96 locations in the helmets.

Of the parameters studied, only thickness was found to have
had both enough variability among and within helmets and sufficient
influence on V_p50 to be of potential value as a replacement for the
ballistic test. The use of thickness as an inspection criterion could
have many advantages over the current V_p50 test. The inspection pro-
cedure could be nondestructive, inexpensive, and relatively rapid;
also, 100 percent inspection might be practical.

At the conclusion of the 1966-67 study, certain key points
remained to be investigated before a replacement of ballistic inspec-
tion could be justified. First, while the relationships obtained be-
tween thickness and V_p50 were highly encouraging, they were not suffi-
ciently strong to justify implementation of the change. There were,
however, indications that further analyses would reveal stronger corre-
lations. Assuming a sufficiently strong relationship existed, two
other basic questions would have to be answered regarding future inspec-
tion plans: Where should thickness be measured? How should it be
measured?

The current two-phase study was directed at these issues.
Phase I had as its objectives (1) further investigation of the V_p50-
thickness correlation, (2) determination of the most appropriate places
to monitor thickness in a helmet, and (3) the formulation of associated
inspection plans. The approach involved, primarily, further analysis
of data obtained under the earlier contract.

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The Phase I study is reported in our Technical Report to Natick Laboratories "Development of a New Acceptance Criterion for M-1 Helmets, Phase I: Analyses of Data and Development of Inspection Plan", dated December, 1968, NLABS No. 72-20-GP, November 1971.

The most significant conclusions drawn from the Phase I study were:

(1) A strong, linear relationship exists between V_p50 (for fragment simulators) and thickness of Hadfield steel as found in M-1 Helmets. The relationship is $V_p50 = 57 + 24,900t$ (V_p50 in fps, thickness, t, in inches). The correlation coefficient for the data was 0.98; the standard deviation of the V_p50 about the line given by the above equation was 17 fps. The V_p50 of a helmet can be computed by substituting average helmet thickness for t in the above equation. Similarly, the V_p50 for any portion of a helmet can be computed by using the corresponding average thickness. The value of V_p50 so computed is a better estimate of the "true" V_p50 than can be obtained by ballistic tests on a single helmet.

(2) Helmet quality, as currently indicated by a minimum acceptance V_p50 of 900 fps, can be maintained if

(a) the average thickness of helmet crowns is no less than 0.034 inch, or

(b) the minimum thickness at any point in a helmet is no less than 0.032 inch.

Although other criteria could be developed (e.g., average thickness of the entire helmet), the above come closest to maintaining the sense of the current inspection.

Based on the above conclusions and the fact that thickness measurements are simpler, more rapid, less expensive and can be made with greater confidence in the results than is the case with ballistic testing, the following recommendations were made in the Phase I report:

(1) That the current helmet inspection based on ballistic testing with fragment simulators (Paragraph 3.4.1.3 of MIL-H-1988E)* be replaced by an equivalent inspection based on thickness.

(2) That the quality characteristic of the new inspection be either (a) average thickness of helmet crowns or (b) minimum thickness in helmets (the choice to be made primarily on the basis of economics of sampling). The lower specification limit would be 0.034 inch if (a) is chosen; it would be 0.032 inch if (b) is chosen.

* Military Specification MIL-E-1988E, Helmet, Soldier's, Steel, M-1 (Complete).

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(3) That the following inspection plan be instituted:

    (a) The current method of selecting helmets for sampling be retained

    (b) A sampling by attributes inspection plan be used

    (c) A sample size of 80 helmets per heat-treatment lot be used

    (d) The lot be accepted if no more than one helmet does not meet the thickness requirements; the lot be rejected if two or more helmets do not meet the thickness requirements.

(4) The current thickness specifications (Paragraph 3.4.1.1 of MIL-H-1988E) be dropped.

The above inspection plan, although having slightly different operating characteristics from the current plan, should assure approximately the same quality helmets without imposing additional stringency upon the producer.

The next step was to investigate the most effective means for implementing the thickness inspection. This was the purpose of Phase II — the current study. Although, in principle, helmet thickness can be measured in any of a number of ways, it is to the Government's interest to have standardized techniques, thus increasing the probability of uniformity of helmet quality from several manufacturers. Also, a well conceived and designed inspection system can reduce inspection costs which, ultimately, will be reflected in helmet costs. The desired system was to have the following characteristics:

(1) It should be appreciably less expensive to operate than the current ballistic inspection.

(2) It should require a minimum of operator judgment and skill and not result in excessive operator fatigue.

(3) It should be sufficiently rapid so that inspection need never lag production.

With these factors in mind, Phase II was initiated with the objectives of (1) identifying the most effective method for making the thickness inspection and (2) preparing a preliminary design of a complete helmet thickness inspection system.

SUMMARY

Several thickness-measuring methods were evaluated to find the most effective means for helmet inspection. Consideration was given to ultrasonics, electromechanical and pneumomechanical devices, radiological methods, and eddy-current methods. Approaches based both on averaging and minimum seeking systems were considered. The evaluations were aided by brief engineering studies and by discussions with instrument manufacturers. The eight most promising systems were considered in some detail. For these, schematic designs were developed. A comprehensive rating chart was used to aid in making a final selection. Factors considered in the selection process included potential accuracy, jig complexity, commercial availability of components, speed of operation, operator hazards, and overall reliability. Based on these considerations, a thickness-averaging ultrasonic system, containing a set of stationary transducers connected to averaging circuitry and digital readout, was selected as most appropriate. The remainder of the study centered on preliminary design of such an inspection system.

The selected system utilizes 16 ultrasonic transducers arranged and mounted so as to monitor the thickness at selected points in the helmet crown. A special feature of the design is provision to assure that the ultrasonic signals are directed normal to the helmet surface (within a 2 degree tolerance) regardless of expected deviations from nominal helmet geometry. In developing the design, attention was given to the overall layout of the equipment and its effect on operational efficiency. Wherever possible, commercially available components were specified. Full-scale layout drawings of the mechanical portion of the inspection system are included in this report.

Two systems, differing only in the degree of completeness of the electronics, are discussed. With the "full system", the helmet is put into the inspection fixture and the average thickness of the crown is printed out a fraction of a second later. The inspection time per helmet lot with this system would be about 1/16 of the time required by the current ballistic method. It is estimated that the first prototype of this full system could be fabricated for about $30,000 ($6,000 for preparation of detailed drawings and fabrication of the mechanical portion of the system and $24,000 for the electronics).

With the "simplified" system, after placing a helmet into the fixture, the 16 thicknesses are read individually and the average thickness is calculated by the operator. The inspection time will be about twice that required from the full system. The total cost of this system would be about $14,000 (the difference being due entirely to the lower cost of the electronics involved).

SYSTEM INVESTIGATION AND SELECTION

The investigation·and selection portions of the program
consisted of an examination of several measuring techniques in the
light of the new inspection criteria, the formulation of schematic
drawings and block diagrams of candidate systems, and the construction
of a comprehensive rating chart to aid in final system selection.

Inspection Criteria

During the Phase I effort, the following inspection criteria
were established, based on a statistical study of ballistic tests on
a sample of 200 M-1 helmets:

(1) Sample Size: 80 helmets from each heat treatment lot,
     the production from each lot numbering (typically)
     from 3000 to 5000 helmets.

(2) Alternative Quality Characteristics and Specification
     Limits:

     (a) A helmet is nondefective if its average crown
          thickness is equal to or greater than 0.034 inch,
          otherwise it is defective, or

     (b) A helmet is nondefective if its minimum crown
          thickness is equal to or greater than 0.032 inch,
          otherwise it is defective.

(3) Acceptance Criterion: The lot is accepted if not more
     than one of the helmets inspected is defective. The
     lot is rejected if two or more are defective.

Inspection Techniques

The inspection techniques given consideration in Phase II
were as follows:

(1) Mechanical, electromechanical, and pneumomechanical
     micrometer methods

(2) Ultrasonic methods

(3) Radiographic methods

(4) Eddy-current methods.

Evaluation of Measuring Techniques

In addition to the study of such alternatives as stationary or scanning modes and average or minimum-seeking criteria, the methods used to evaluate the proposed inspection techniques included estimates of point measurements, and the generation of schematic designs of systems employing the various measurement techniques.

Stationary and Scanning Modes

Supplementary to selecting among several alternative measuring techniques, it was recognized that either a scanning mode or a stationary array of sensors might be applicable with a given technique. In the scanning mode, a single sensor is moved over the helmet surface, either to generate an average thickness reading or to seek a minimum thickness. In the stationary mode, a fixed array of sensors is used to provide similar information by means of parallel rather than serial processing. In general the scanning mode is slower, requires continuous driving mechanisms in the jig, and is susceptible to unwanted signal variations due to relative motion between the sensor and the helmet. The stationary array mode is potentially faster and free from the complications of scanning drives, but requires multiple sensors.

Average and Minimum Criteria

Another factor involved in system selection was the criterion to be used. According to the Phase I results, either the average thickness or the minimum thickness criterion can serve independently as an indication of quality. In setting up the schematics of candidate systems, two versions were shown in cases where either the average or the minimum could be detected with comparable ease. In one case, the diffused radiographic system, only the average criterion was applicable because of the physical nature of the process.

Accuracy Requirements

To define the expected accuracy of an average based on a number of individual measurements, it is necessary to consider both the number of points involved and the accuracy of the individual measurements. An investigation of the number of point measurements needed to obtain a realistic average thickness of a helmet was conducted using the data from Phase I. The average thickness computed from the center points of the 16 zones comprising the crown (bands A, B, and C in Figure 1) was compared with the average computed from the original

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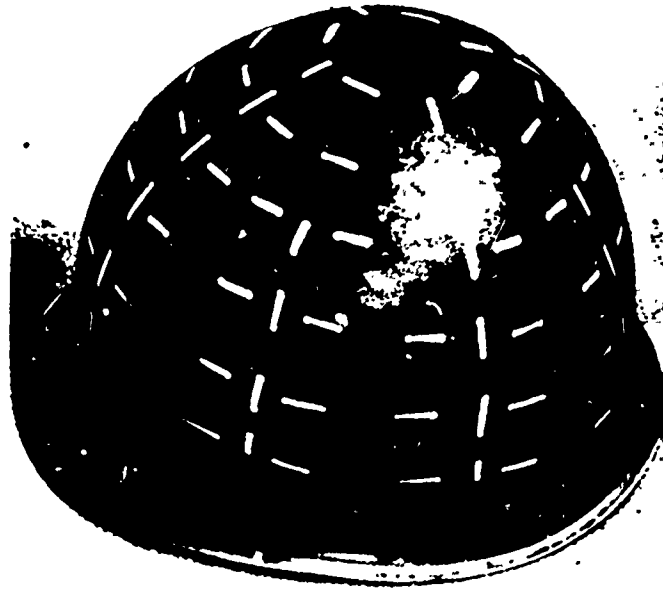
a. Photograph of Helmet With Zones Laid Out
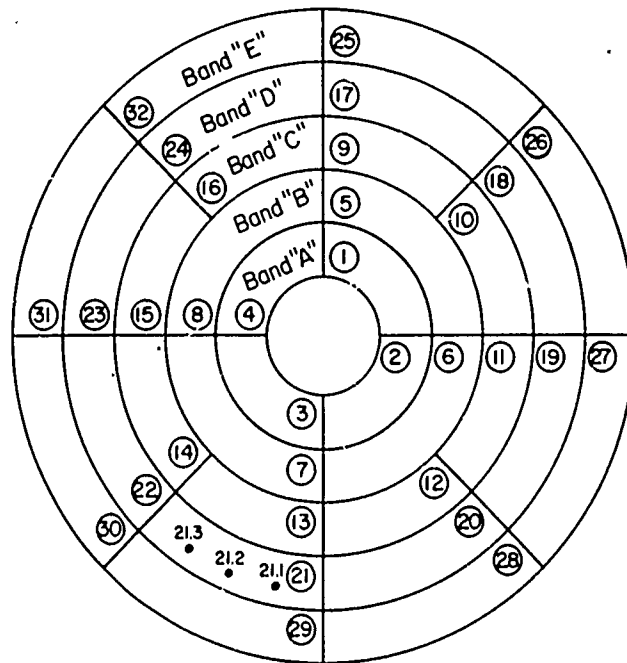
b. Map of Helmet (Zone Numbers Are Circled)

FIGURE 1. COORDINATE SYSTEM FOR HELMETS

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48 points for each of the 200 helmets of the earlier study.* The __maximum__ difference between the two averages was found to be about 0.0003 inch. The algebraic average of the differences was approximately 1×10^{-6} inch, indicating a negligible bias favoring high or low values. The average of the absolute differences was 0.00007 inch, and the standard deviation of the differences about this value ·was 0.00005 inch. On the basis of these findings, it was concluded that a very satisfactory value for average thickness can be obtained from 16 measurements taken at the nominal zone centers. A similar analysis based on the twelve points specified in MIL-H-1988E (as points of impact for the ballistic inspection) provided the following data: algebraic average difference between 12 and 48 point average, plus 0.0001 inch; average of absolute differences, 0.0002 inch; standard deviation of absolute differences, 0.0001 inch; maximum difference, 0.0006 inch. Although the 12-point results were good, it was decided that the 16-point average was worth retaining in view of the two-fold reduction of standard deviation in return for a 30 percent increase in the number of points measured.

Taking the crown average thickness based on the 48 original measurements as the "true" average, the precision required for each of the 16 point measurements was estimated. First, it was assumed that the average was desired to within ± 0.0005 inch, corresponding to a tolerance of ± 12 feet per second on the V_p50 figure. This assumption was applied by taking 0.0005 inch as the three-standard-deviation (3-sigma) range of the allowable instrument error, neglecting the small contribution to standard deviation due to the difference between the 16-point and 48-point averages. The corresponding 3-sigma range on individual measurements was found from the well-known relation that the individual measurement tolerance is given by the desired tolerance on the average times the square root of the number of points used to form the average:

$$\pm\ 0.0005\ \sqrt{16}\quad =\ \pm\ 0.002.$$

Thus the required instrument tolerance was found to be ± 0.002 inch. Most of the measuring methods considered were capable of a tolerance of ± 0.001 inch or better. A rule of thumb frequently used in metrology is that a measuring system should be capable of sensing quantities one order of magnitude smaller than the nominal tolerance on the measurement. This criterion is known to be met by techniques such as ultrasonics and mechanical gaging, which can resolve increments at least ten times smaller than the nominal requirement. The ability of radiographic and eddy-current instruments to meet this criterion was found to be less well documented, but not out of question.

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* In the initial study, thickness was measured at three approximately equally-spaced points in each of the 32 numbered zones in Figure 1. A recommendation based on the Phase I study was that the thickness inspection be limited to the 16 zones in bands A, B, and C.

In the case of minimum thickness as a quality characteristic, the development of a required tolerance is not as straightforward as it is for the average criterion. This arises partly from the fact that the minimum thickness is a local rather than a distributed property. If it is assumed that the entire crown surface is scanned, then the tolerance for ± 12 fps on V_p50 becomes simply ± 0.0005 inch. In practice, a system that approaches this ideal tends to be very slow unless the scanning rate is very rapid, which in turn introduces mechanical difficulties and noise problems. If the scan is continuous but does not cover the entire crown, or if discrete measurements are taken, there appears to be no simple method for determining the scan line spacing or number of points needed for a given accuracy on the minimum. It is clear, however, that 48 points would be capable of defining the minimum as closely as the original data from which the minimum criterion was developed.

Schematics and Block Diagrams

In the following sections, schematics of the 8 candidate systems considered in the program are shown, and their relative merits discussed. In cases where industrial contacts or special sub-studies were made, these are summarized. The systems employ mechanical (including air and LVDT probes), radiographic, ultrasonic, and eddy-current measuring techniques. In most cases alternate systems are presented for each measuring technique, one based on the average thickness acceptance criterion and another based on the minimum criterion. Generally the averaging systems employ an array of fixed sensors, while the minimum-seeking systems utilize a single sensor and a scanning mechanism. However, one mechanical and one radiographic system depart from this rule.

Mechanical Averaging System. An averaging system using mechanical gaging devices is illustrated schematically in Figure 2. Sixteen sensors are used to obtain point measurements at the approximate centers of the 16 crown zones defined in Figure 1.   Since it is easier to average accurately large numbers of electrical signals than large numbers of pneumatic signals, LVDT* sensors are shown. The averaging unit can be either entirely analog, or digital with built-in analog-to-digital conversion for the LVDT signals. The use of differential pairs of sensors is helpful because, if properly matched for equal-slope responses, they are not affected by shifts in position of the section being measured, as long as the shifts are normal to the probe axis and do not move either sensor beyond its linear range. This property is useful in allowing for helmet-to-helmet size variations and jigging errors.

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* LVDT stands for Linear Variable Differential Transformer, an electrical induction device capable of measuring small displacements with excellent linearity and repeatability.
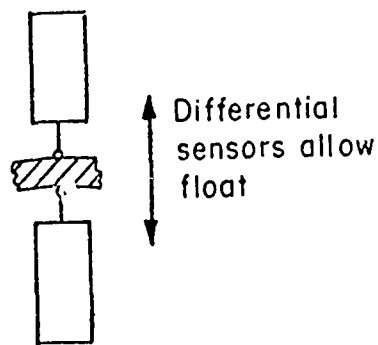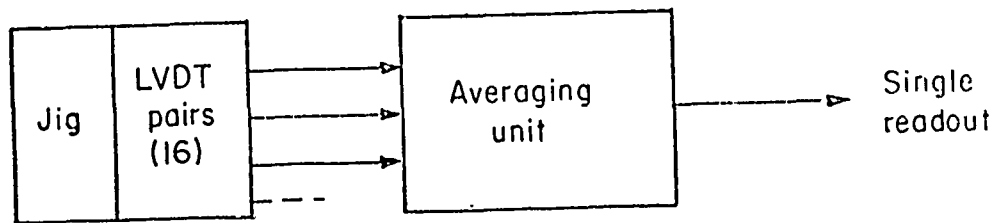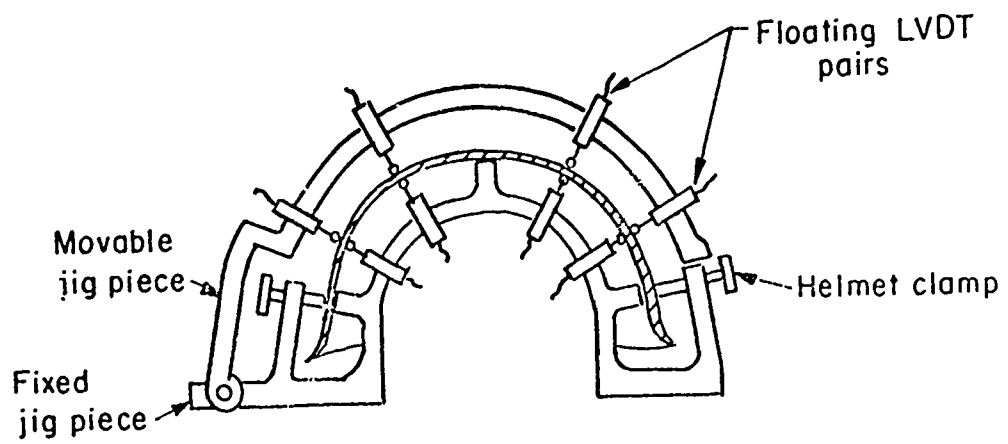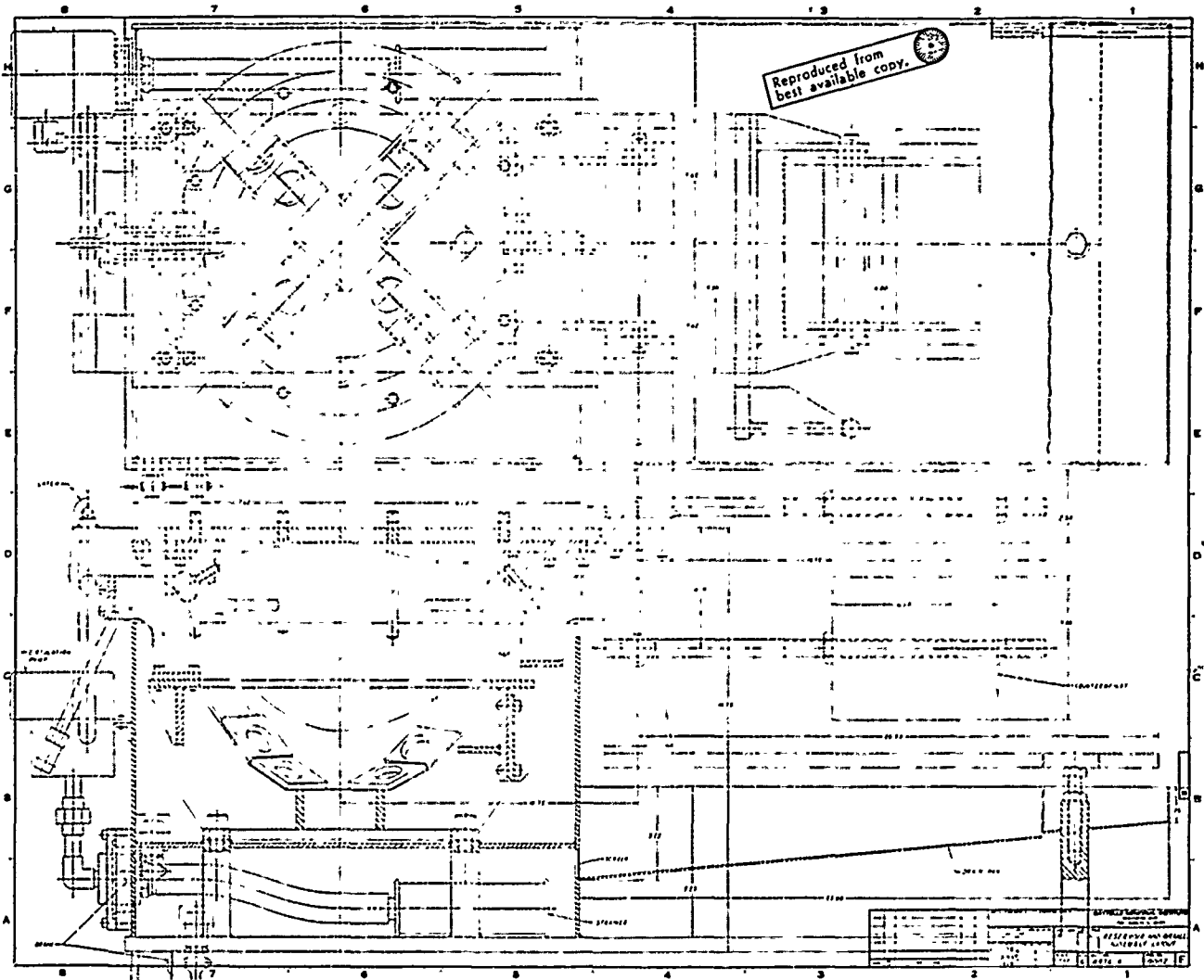
Floating LVDT pairs

Movable jig piece

Helmet clamp

Fixed jig piece

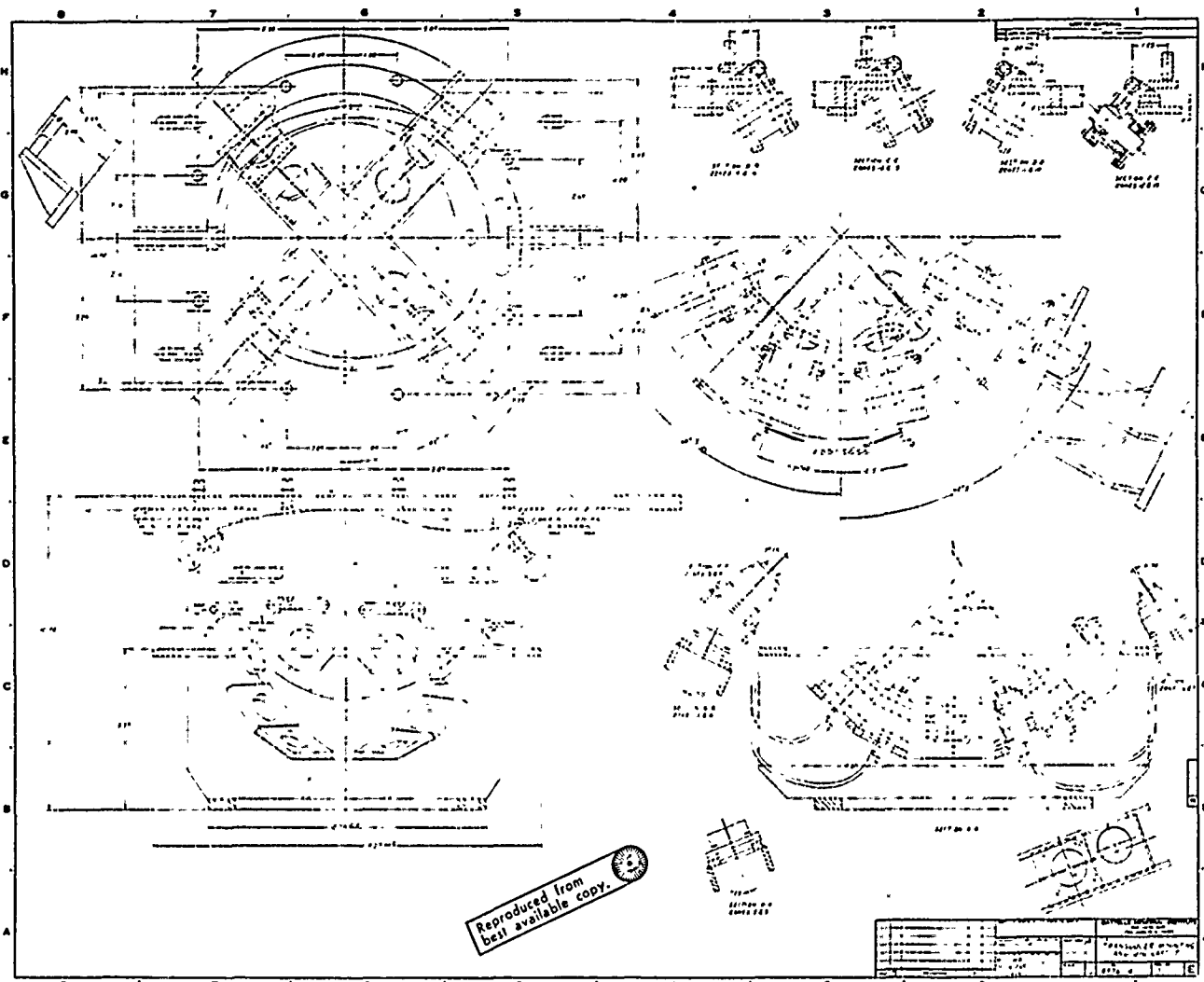| Jig | LVDT pairs (16) | → | Averaging unit | → | Single readout |

Differential sensors allow float

Figure 2. Mechanical Averaging System

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Mechanical Minimum System, Non-Scanning. Figure 3 is a block diagram for a non-scanning, minimum-seeking mechanical system. The jig configuration would be similar to that of Figure 2, but more sensor pairs would be used, the upper limit being 48 pairs. Since averaging is not required, relatively inexpensive air probes and columnar flow-meter readout devices are appropriate. The measurement display is a row of vertical columns with a limit line representing the minimum allowable thickness. A quick visual scan indicates whether the minimum limit is passed at any point. The air sensor probes are actually precision valves, similar in size and appearance to LVDT's, and can be used differentially as shown in Figure 2. The resolution available can readily be extended to 0.0001 inch or better. Unfortunately, however, the linear range (usable stroke) is inversely related to the fineness of resolution. For example, it was found that a typical pair of air probes would have a floating range of only 5 mils if used to cover a thickness range from 0.030 to 0.045 inch at a sensitivity of 0.0005-inch-per-readout division. This is not sufficient to allow for expected shape variations among helmets. The characteristics of LVDT- and air-probe-based systems were examined during a visit to the Automation and Measurement Division of Bendix (makers of Sheffield products) in Dayton.

Mechanical Minimum System, Scanning. Figure 4 shows a mechanical minimum system based on a scanning sensor. The helmet is clamped in the azimuth axis mount, and the azimuth and elevation drives are geared together to produce a spiral scanning pattern over the helmet crown. The single sensor pair, either LVDT's or air probes, is mounted on the elevation scan frame in such a way that changes in helmet radius and surface normal inclination can be accommodated. The normalizing means shown schematically, as an example, uses magnets which clamp to each other through the non-magnetic helmet material and align the probes with the local surface normal. As indicated in the block diagram, the readout could be recorded conveniently on a continuous chart with a limit line indicating the permissible minimum.

Diffused Radiographic System. The point source radiographic system shown in Figure 5 was suggested by Dr. Robert Pfeifer of the Industrial Nucleonics Company in Columbus. The intent of the design is to generate an average thickness reading directly. A set of Geiger-Muller (GM) tubes, perhaps 10 or 12, is arranged around the helmet crown. Each GM tube is connected to a pulse-shaper which can be connected to a digital counter. A gamma-radiation source, for example, Americium-241, is placed at the mean center of curvature of the crown. To make a measurement, the count rate from each GM tube is totaled over a give time interval, and the totals added to form a number related to the average thickness of the crown. The degree of correlation between the totalized count and the average thickness depends on the number and arrangement of the detector tubes, the counting period, the strength of the source, and the repeatability of helmet shape and position. An initial calibration curve could be established from a graded set of helmets of known average thickness.

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A

LATCH

CIRCULATION PUMP

SCREEN

STRAINER

DRAIN

DRAIN

37

COUNTERWEIGHT

SCREEN

DRAIN PAN

STRAINER

RESERVOIR AND OVERALL
ASSEMBLY LAYOUT
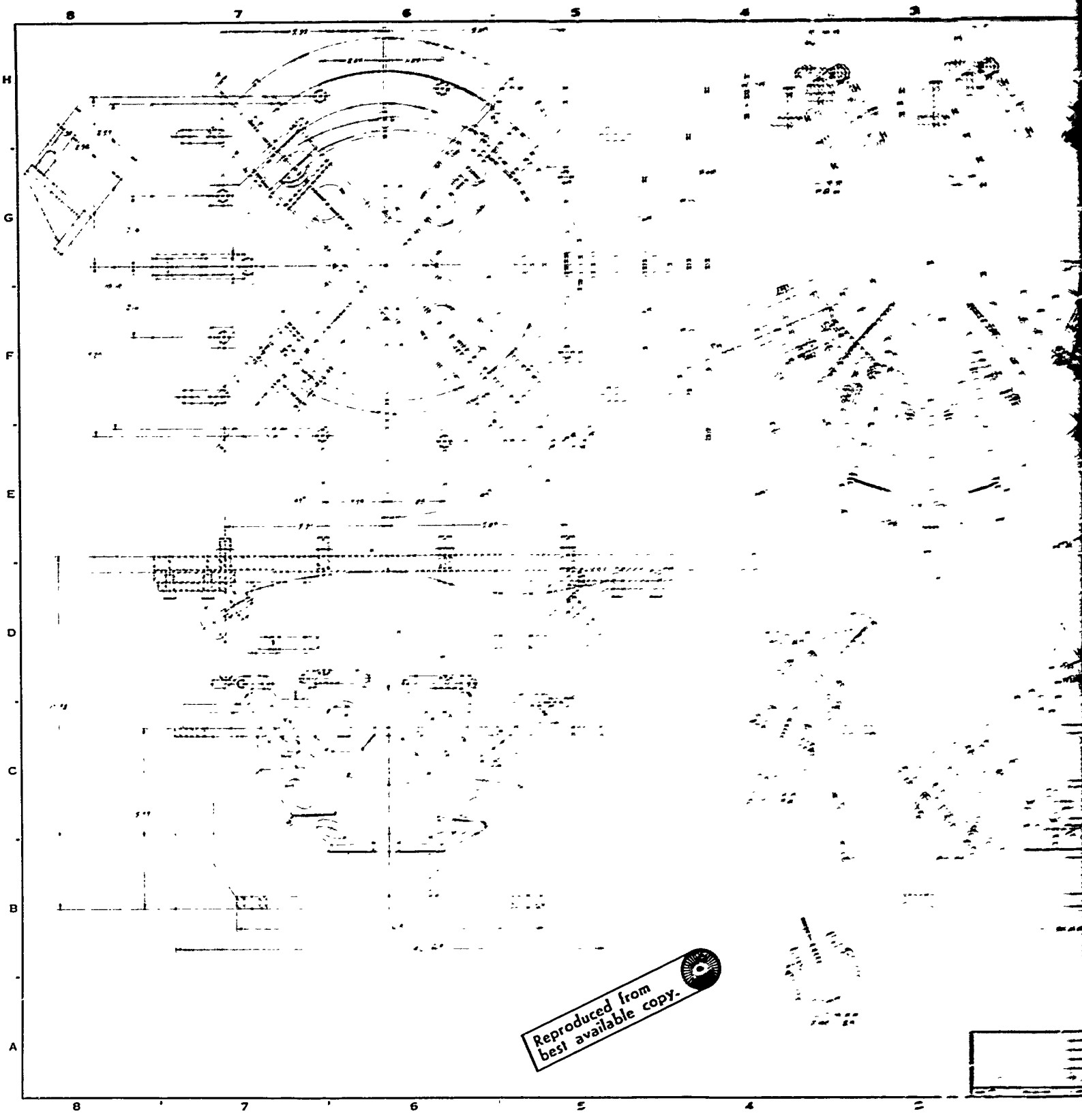
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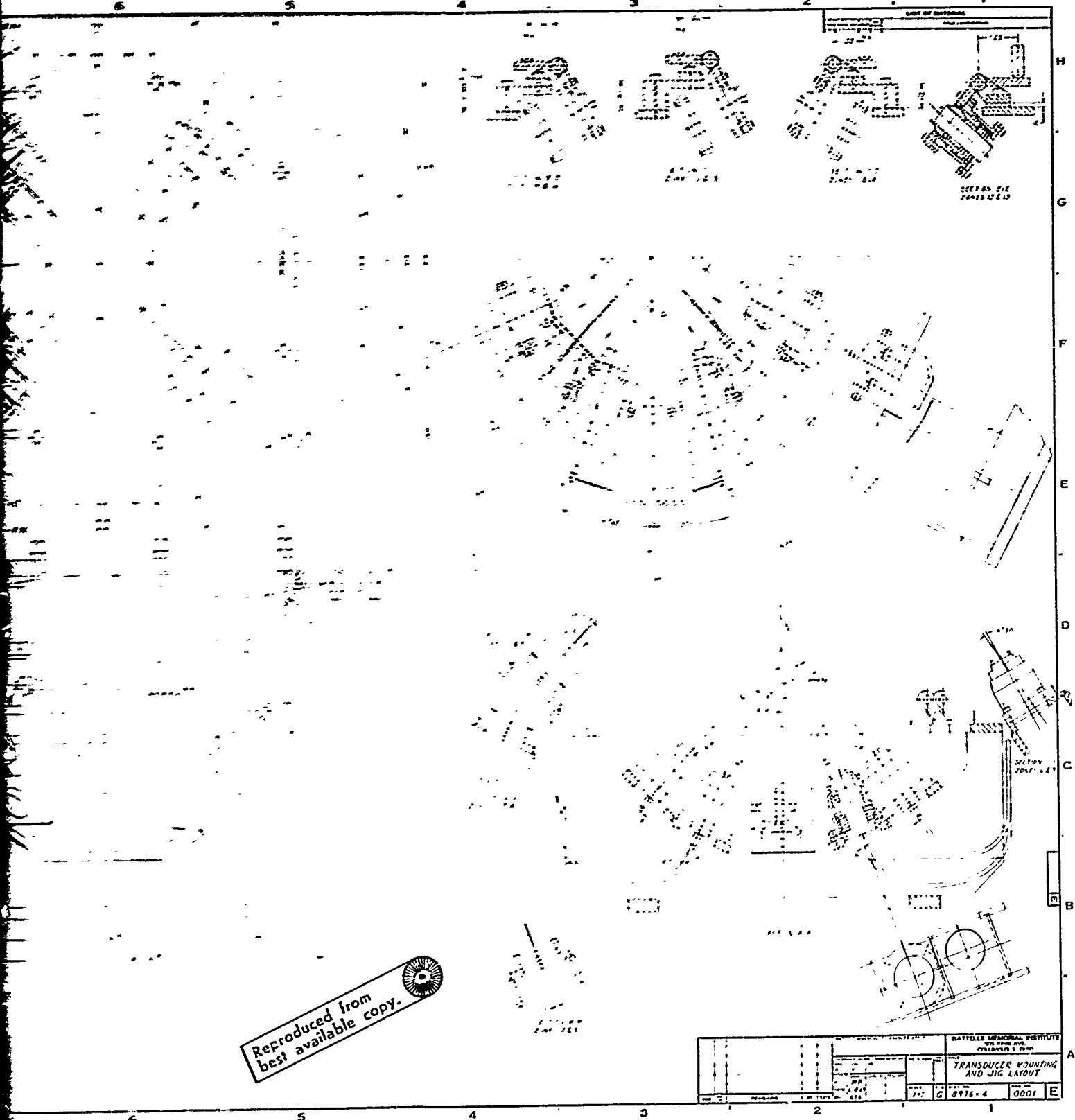
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Figure 3. Mechanical Minimum System, Non-Scanning

Figure 4. Mechanical Minimum System, Scanning

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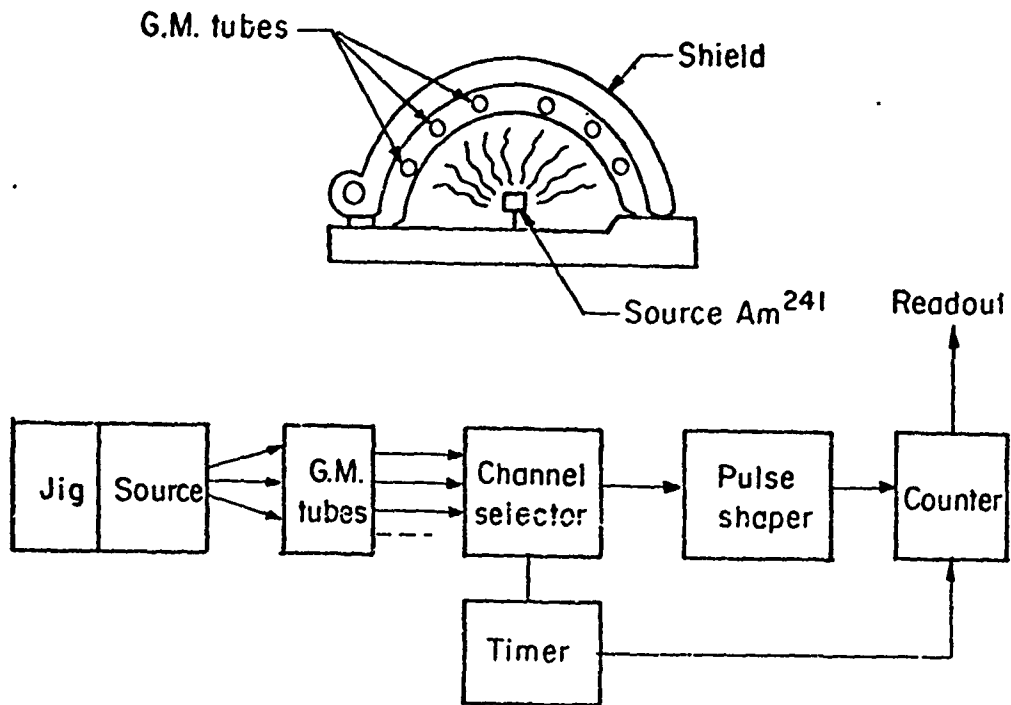
Figure 5. Diffused Radiographic System
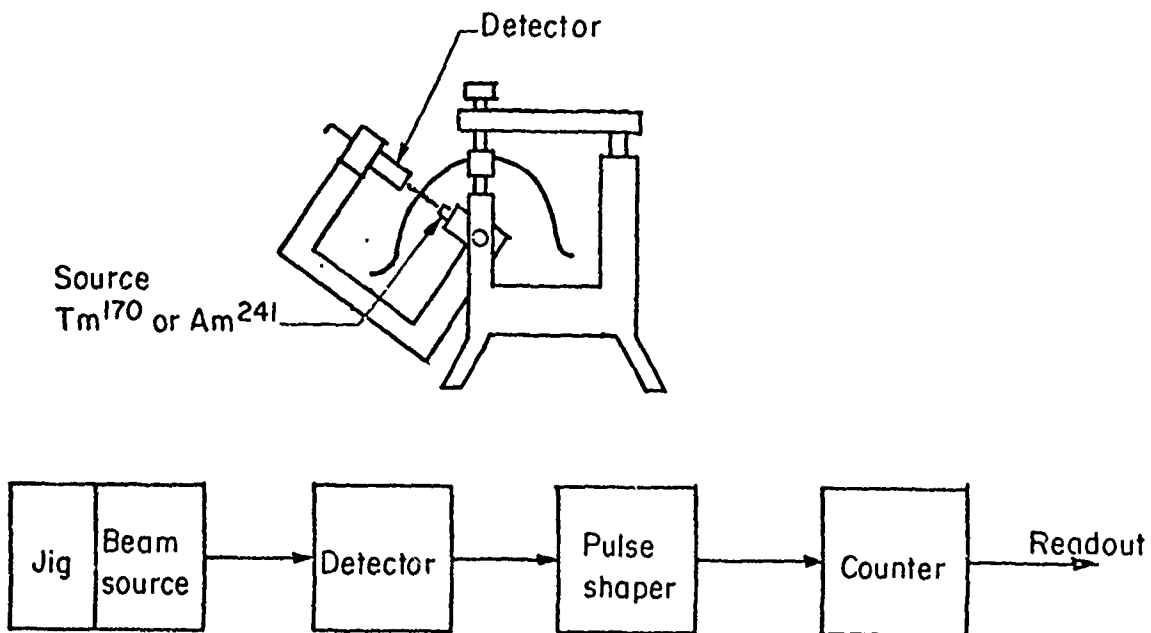
Figure 6. Beamed Radiographic System

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Although helmets would not become radioactive, some shielding would be required to protect the operator from the source during and between measurements. It was estimated that a measuring or counting time of 1 to 10 seconds per channel (per GM tube), with a source producing about 2 milliroentgens per hour at the tubes, could give a measuring resolution of about 1 mil. A stronger source or longer measuring time would increase the accuracy. The primary drawbacks of a system of this type arise from the rather extensive development necessary to test the principle, and the probable sensitivity of the system to small changes in helmet shape and position.

Beamed Radiographic System. A second type of radiographic measuring system, shown in Figure 6, resulted from a brief feasibility study made at Battelle. A collimated beam of gamma radiation is directed through a spot on the helmet crown to a detector held rigidly coaxial with the beam. A scanning jig mechanism is used to sweep or incrementally position the beam over the crown surface. It was estimated that, assuming the instrumentation errors to be equal to or less than one-half the normal statistical variation in disintegration rate, the beamed-source configuration would provide thickness readings within 0.0008 inch, based on 4000 counts-per-second for 5 seconds at each location tested. A rough graphical check of the maximum thickness error due to the non-spherical helmet shape indicated a value of 0.0005 inch. This would be satisfactory for an averaging system, but marginal for a minimum-seeking system. As with the point-source system, radiation shielding would be required.

Ultrasonic Averaging System. The ultrasonic averaging system shown in Figure 7 has the distinct advantage that no sensors or other gaging apparatus need be located inside the helmet. A coupling fluid such as water is, however, required to transfer the high-frequency pressure waves efficie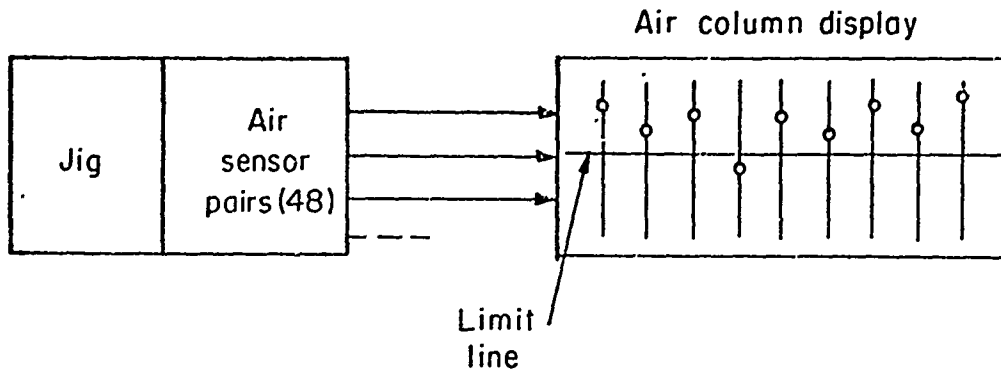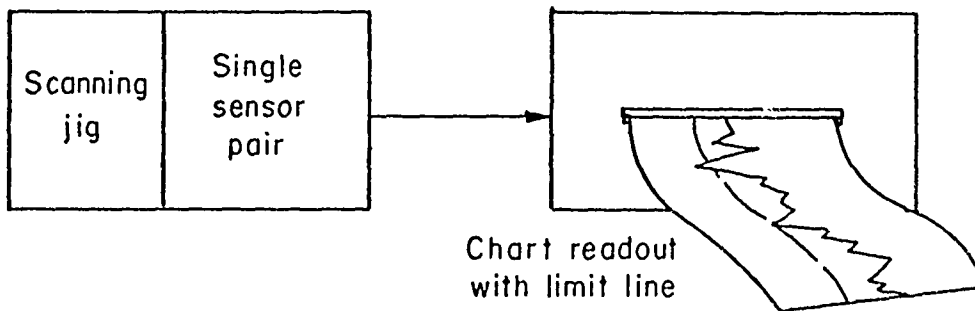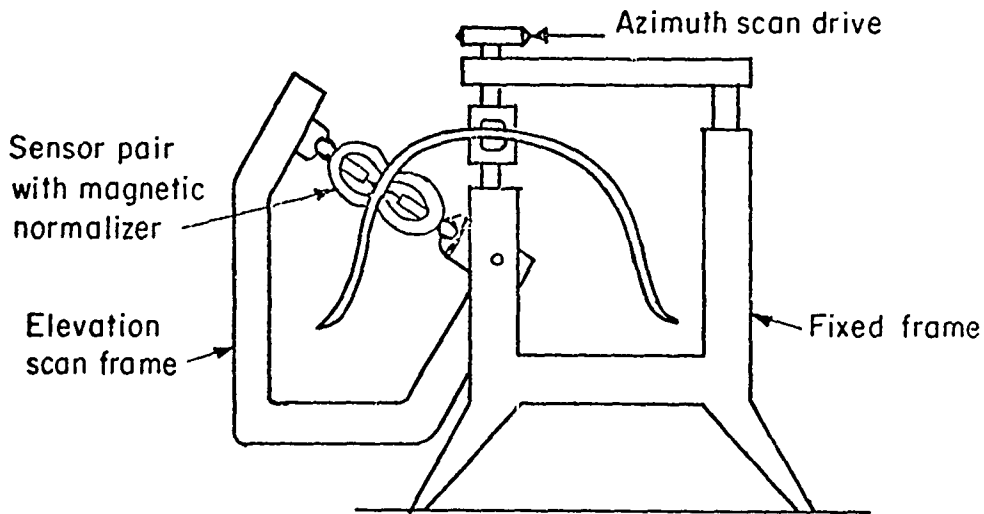ntly from the transducers to the helmet surfaces and back. Of the companies contacted (Automation Industries Inc., Branson Instruments, Inc., and Krautkramer Ultrasonics), only Branson Instruments offered essentially off-the-shelf equipment capable of measuring thicknesses in the 30-to 40-mil range with a sensitivity of 0.0001 inch.

The principle of operation of the equipment is as follows: a very short duration pulse is generated by the transducer and beamed toward the helmet. Two "echoes" are generated, the first when the wave front strikes the outer surface and the second when it strikes the inner surface. The echoes are sensed by the transducer, which acts as both transmitter and receiver. An electronic timer measures the interval between the first and second echoes, which is twice the transit time for a sonic wave through the helmet material. The thickness of the material is the product of the transit time and the speed of sound in the helmet material.

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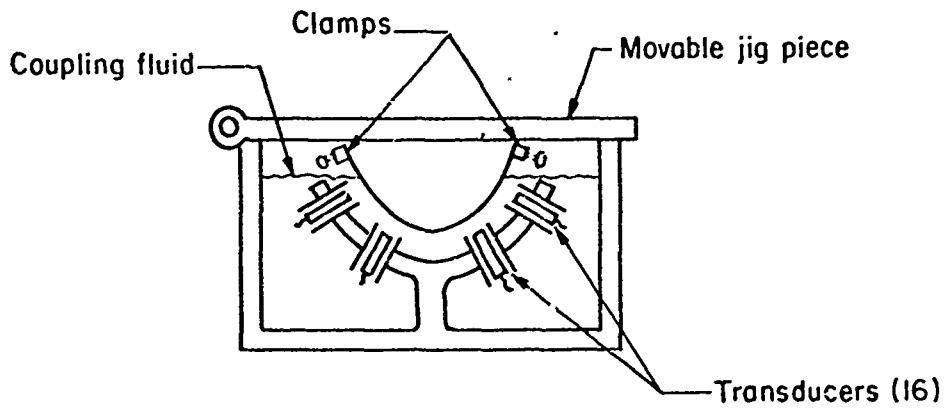
Figure 7. Ultrasonic Averaging System
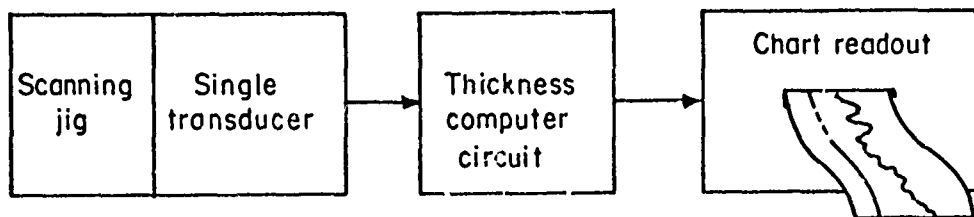
Figure 8. Ultrasonic Minimum System
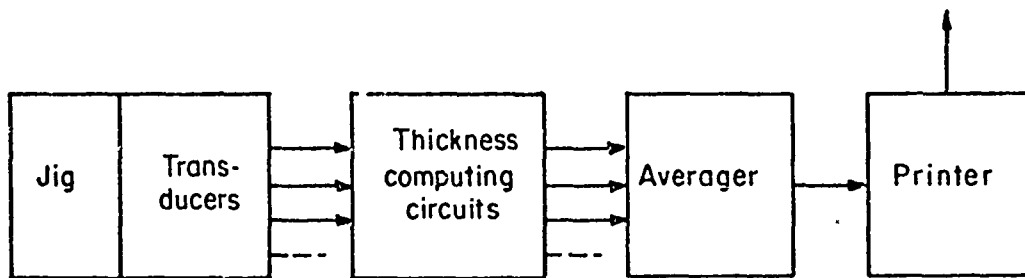
16

Early in the program, a Branson Model 101 "digital caliper" was tried on a sample helmet shell. Although only roughly calibrated, the unit produced stable readings consistent with the known thickness range of the material. Some difficulty was experienced with the oil drops used for coupling. This problem should not occur with the recommended system, in which the helmet and transducers are submerged in the coupling fluid.

An additional advantage of the ultrasonic method over mechanical probes is that the sensors themselves (piezoelectric crystals) do not need to contact the helmet surface. In fact, the measurement is insensitive to moderate changes in distance from the crystal to the helmet. However, high reliability in detecting the reflected signals requires that the transducer axes be aligned within about two degrees of the true surface normal at the measuring point. To insure that this condition is maintained regardless of helmet-to-helmet variations, it was decided to equip each transducer with a three-point base and limited range ball pivot, providing self-normalizing capability over a cone angle of ± 5 degrees. These details are not shown on the schematic diagram.

The block diagram of Figure 7 shows a fast, parallel-processing system in which a thickness computing circuit (essentially a precision timer) is provided for each transducer. The transducers are fired simultaneously or in very rapid sequence, and the outputs from the computing circuits are digitally averaged to give a direct readout (for example, on numeric display tubes or via automatic printer) of the quality criterion. A slower but less costly system would require only one computing circuit, which would determine the thickness at each transducer station in a sequence governed by either hand or automatic switching. No averaging circuit would be used, and the operator would record data from each transducer in turn.

Ultrasonic Minimum System. Figure 8 shows the block diagram for an ultrasonic system based on the minimum criterion. The jig would be similar to that shown in Figure 4, except that the transducer would be applied to the outside only, and the entire unit would be submerged in the coupling fluid.

Eddy-Current System. A block diagram for an eddy-current system is shown in Figure 9. A brief study of the compatibility of the M-1 helmet material (Hadfield Steel) with eddy-current techniques indicated that such a system probably could be made to measure thickness within 0.0005 inch. Since this accuracy level is more appropriate to an averaging system than a minimum system, a jig similar to that of Figure 7 is assumed. Like ultrasonics, the eddy-current method is capable of measuring thickness from one side. The transducers would be a set of probe coils excited in the radio-frequency range. The major drawbacks of such a system are the evident lack of available

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Readout

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┌─────┬──────┐    ┌──────────┐    ┌─────────┐    ┌─────────┐
│     │ Probe│ ─→ │Thickness │ ─→ │         │    │         │
│ Jig │ coils│ ─→ │computing │ ─→ │ Averager│ ─→ │ Printer │
│     │ (16) │ ─→ │ circuits │ ─→ │         │    │         │
│     │      │----│          │----│         │    │         │
└─────┴──────┘    └──────────┘    └─────────┘    └─────────┘
```
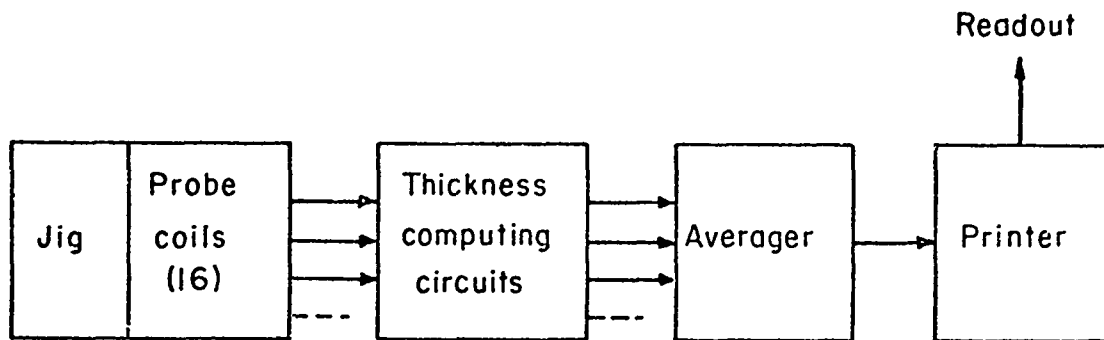
Figure 9. Eddy-Current Averaging System

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commercial equipment designed specifically for thickness measurement, and the need for further verification of potential accuracy and sensitivity.

Rating Chart

A comprehensive rating chart was drawn up as an aid to selecting a system from among the eight candidate systems. The rating chart in final form is shown as Table 1. The first column contains the 12 criteria on which the ratings were based, such as expected accuracy, degree of development needed, operator convenience, etc. The second column, headed "Values", contains guide words or numbers which indicate whether a criterion is met favorably, neutrally, or unfavorably by a given candidate system. For example, under "Speed of Operation" a value of +1 is assigned if the system is capable of rapid measurement, 0 if it is moderately fast, and -1 if it is compara- tively slow. The guide words are arranged so that systems which are strong in a criterion favorable to effective performance receive a value of +1, and those which are strong in an undesirable criterion, such as "Operator Hazard", receive a -1.

The column headed "Weighting Factors" serves as a means for recognizing that some criteria are more important than others to system performance. For instance, it was judged that accuracy and reliability were more important than operator convenience or jig complexity. The use of 10 and 5 for weighting factors is arbitrary, and the final rating hierarchy would be unchanged if 2 and 1 had been used instead.

The last eight columns present the actual ratings. Each column represents one of the systems described above. The rating num- bers consist of the product of the assigned value and weighting factor for each system under each criterion. As an example, consider the ultrasonic averaging system with regard to "Development Needed". Since the instrumentation required to measure material of the curva- ture and thickness range of the M-1 helmet is commercially available as standard equipment, it was judged that the amount of development needed is comparatively low. This gave a value of +1, which was multiplied by the weighting factor of 10 to give the rating number shown.

The total score for each system is the sum of the rating numbers in its column, as shown at the bottom of the chart. A "per- fect" score, indicating +1 values for all 12 criteria, would be 90. The lowest possible score would be -90; hence a score of zero would indicate a mediocre system rather than an exceptionally poor one. The results gave the highest rating, 55, to the ultrasonic averaging system. The mechanical averaging system (LVDT-based) and mechanical minimum (non-scanning) were next with totals of 35 and 30, respec- tively. Some factors contributing to the high rating for the

Criteria	Values +1	Values 0	Values -1	Weighting Factors	I. Mech., avg.	II. Mech. min., no scan	III. Mech. min., scan	IV. Radio. Diff., avg.	V. Radio. Beam, avg. or min.	VI. Ultra-sonic, avg.	VII. Ultra-sonic, scan	VIII. Eddy Current
1. Accuracy	±0.0001 to ±0.0005	±0.0005 to ±0.001	±0.001 to ±0.010	10	10	10	10	-10	-10	10	0	-10
2. Jig complexity	Low	Moderate	High	5	0	-5	-5	5	0	5	-5	5
3. Signal Processing Complexity	Low	Moderate	High	5	-5	5	0	0	0	-5	0	-5
4. Development Needed	Low	Moderate	Extensive	10	0	10	0	-10	-10	10	0	-10
5. Speed of Operation	High	Medium	Low	10	10	10	-10	0	-10	10	-10	0
6. Operator Convenience	High	Moderate	Low	5	5	0	0	0	0	0	0	0
7. Operator Hazard	Low	Moderate	High	5	5	5	5	-5	-5	5	5	5
8. Reliability of Readings	High	Medium	Low	10	10	10	0	0	0	0	-10	0
9. Frequency of Calibration	Low	Medium	High	10	10	0	0	0	0	10	0	0
10. Cost	Low	Medium	High	5	-5	0	0	0	0	-5	0	0
11. Sensitivity to Helmet Shape Variation and Jigging Accuracy	Low	Moderate	High	10	0	-10	10	0	0	10	0	0
12. Non-Contacting	Yes	-	No	5	-5	-5	-5	5	5	5	5	5
Totals					35	30	5	-15	-30	55	-15	-5

TABLE 1. COMPARATIVE RATING CHART FOR MEASURING SYSTEMS

ultrasonic system were high accuracy potential, low degree of development required, capacity for rapid operation, and relative insensitivity to jigging errors and variations in helmet dimensions.

It is recognized that the rating chart technique, in spite of its numerical results, contains arbitrary features and frequently requires subjective judgments in the assignment of values and weighting factors. However, it has the advantages of helping to avoid oversight of important criteria, and of requiring all candidate systems to be evaluated on a uniform basis. The chart also provides a means by which choices involving many variables may be documented in compact form.

The results of the system evaluation were discussed in a meeting at the Natick Laboratories on March 20, 1969. A decision was made to initiate design work on the ultrasonic system, with provisions for adoption of either the full system or a simplified version using a single computing circuit for the 16 transducers, as described previously.

PRELIMINARY SYSTEM DESIGN

During the final portion of the Phase II program, a preliminary design for an ultrasonic averaging system was worked out and carried to the layout stage. Since the electronics for either the full system or the simplified version consist mainly of purchased items, most of the engineering effort was devoted to the design of the transducer-holding jig, helmet mounting arrangement, and coupling-fluid reservoir configuration. The design process, for descriptive purposes, has been divided into six areas. These are coordinate specification, transducer mounting, helmet mounting, reservoir configuration, ultrasonic instrumentation, and specifications for materials, purchased items, and costs. The mechanical design of the system is illustrated in reductions of the full-size layout drawings, numbered 0001 and 0002 located at the end of the report text.

Coordinate Specification

Helmet Measurements

Since the transducer mountings were to be designed to be self-normalizing within a limited range, it was decided that data based on measurements of a sample helmet would be accurate enough for layout purposes. A sample helmet was cleaned, blued with machinist's cye, and zoned over the crown in accordance with MIL-H-1988E. The zone centers were marked and the helmet clamped to a base plate. The point of intersection of a perpendicular dropped from the zone origin (the uppermost point of the crown as defined in MIL-H-1988E) with the base plate was taken as the origin of a 3-axis rectangular coordinate system with the base plate as the X-Y plane. Using a surface table and an angle plate to which the base plate could be clamped, the X, Y, and Z coordinates of the zone centers were determined with a vernier height gage. Coordinates were found for all 16 zones in order to check the degree to which the expected bilateral symmetry of the helmet was actually realized. A second set of measurements was taken by erecting a tripod normal-finder of 1.0-inch base circle and 2.0-inch height at each zone center. Measurements taken at the normal-finder tip gave a second set of X, Y, Z coordinates which, taken with the first set, defined the normal to each zone center as a line in space. Since the first measurements had showed that the helmet was sufficiently symmetrical for the purpose at hand, the second set was restricted to one half of the crown, namely zones 3, 4, 7, 8, 13, 14, 15, and 16.

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Coordinate Transformation

To put the measured coordinates into a form convenient for layout visualization and dimensioning, the original data were transformed to the form shown in Figure 10. P_1 and P_2 are the original (X, Y, Z) data points for the ends of a 2-inch segment of a zone center normal. $P_0 = (X_0, Y_0)$ is the point at which the extended normal intersects the X - Y base plane, and O is the origin of the original measurements. If the helmet were a sphere, P_0 and O would be coincident for all zones. R is the "local radius" of the helmet, i.e. the distance from the base plane to the surface of the helmet, measured along the surface normal. Alpha is the elevation angle of R from the base plane, and Beta is the azimuth angle of the plane of R and its base-plane projection, referenced to the Y - Z plane. The coordinate transformations were programmed and performed on a General Electric time-share computer terminal. Table 2 gives the original and transformed coordinate data, rounded to 3 significant figures.

Transducer Mounting

The design approach adopted for transducer mounting was threefold:

1. Coordinate measurements taken from a sample helmet are considered adequate for primary alignment and positioning with respect to the central normals of the inspection zones.

2. Secondary or final alignment is to be secured by means of a mechanical tripod normalizer attached to the transducer. The transducer mounting must allow sufficient angular freedom for the normalizer to operate. The reasons for the secondary alignment freedom are to accommodate shape differences among helmets and errors in helmet positioning. The tripods of the outer eight transducers would encounter considerable rubbing as the helmet was inserted, which could lead to excessive tripod wear and, more seriously, failure of the tripods to achieve 3-point contact because of frictional drag forces on the legs. Therefore, the outer mounting pads are hinged, keeping the tripods from contacting the helmet surface until closure of the jig is nearly complete.

3. The mounting pads for the inner eight transducers (those nearest the top of helmet) can be fixed, since the amount of rubbing produced as the helmet is lowered into the array will be small.

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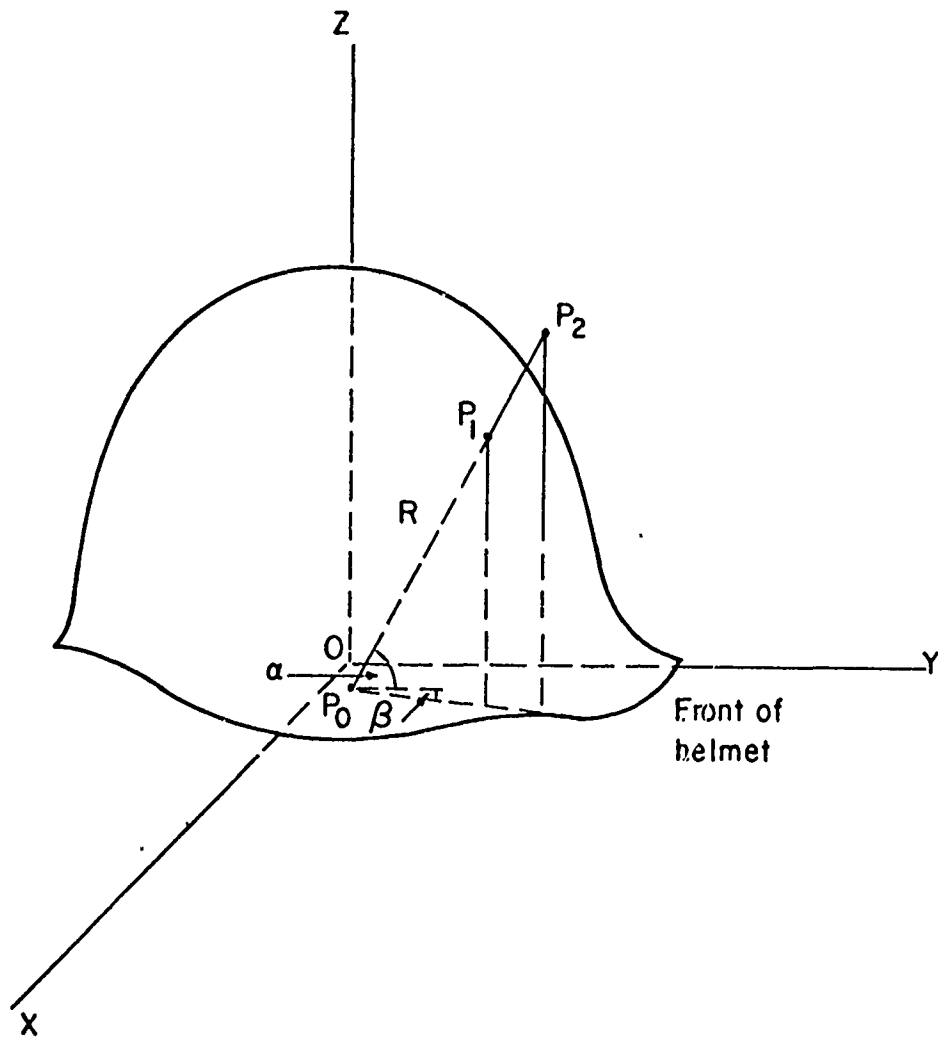
Figure 10. Transformed Coordinates

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Zone	X_1	Y_1	Z_1	X_2	Y_2	Z_2	X_o	Y_o	Alpha	Beta	R
3	1.30	1.31	6.21	1.83	1.77	8.10	-.429	-0.201	69.7	48.9	6.62
4	1.29	-1.30	6.21	1.93	-1.88	7.99	-.942	0.744	64.0	-47.5	6.91
7	2.08	2.09	5.62	3.05	2.74	7.24	-1.29	-0.177	34.2	36.1	6.93
8	2.00	-2.03	5.46	3.06	-2.97	6.93	-1.90	1.45	46.2	-48.3	7.56
13	1.51	3.64	4.92	2.22	4.98	6.25	-1.12	-1.29	41.3	28.0	7.44
14	3.39	1.44	4.54	5.05	1.80	5.55	-4.05	-0.190	30.8	77.9	8.85
15	3.29	-1.37	4.40	4.95	-1.99	5.36	-4.36	1.53	28.3	-69.3	9.22
16	1.39	-3.37	4.52	2.03	-4.09	5.34	-1.48	3.31	30.3	-21.7	9.95

Table 2. Original and Transformed Coordinate Data for the Zone-Center Normals (Other Half of Helmet is Mirror-Image). All Dimensions in Inches, Angles in Degrees.

Expected Performance of Tripod Normalizers

The function of the tripod normalizers is to align the transducers in accordance with local conditions, thus allowing for moderate changes in slope from the nominal values based on measurements of a sample helmet. Before such devices could be used with confidence, however, it was necessary to know whether the expected accuracy of the tripod itself was sufficient to align the transducer within the 2-degree tolerance required for good ultrasonic echo reception. This problem arose because of the marked non-sphericity of the helmet. The ability of a tripod to define the true surface normal at a given location depends (a) on the base circle of the tripod and (b) on the degree to which the surface is non-spherical at the chosen location. As the base circle of the tripod approaches zero radius, it defines the normal to any smooth surface more and more closely; however, the tripod becomes less and less stable. In addition, since the tripod should not interfere with the ultrasonic beam, a practical lower limit on the base circle diameter is imposed in the present application.

To estimate the expected normalizing errors at the various zone centers, tests were made on a sample helmet with the 1-inch base circle device used for the coordinate measurements. The tripod was centered in each zone and rotated through all possible positions while maintaining 3-point contact. The largest distance, or "runout", across the closed path described by the erected tip was measured with a scale, and in the worst case (Zone 7) recorded by using the normalizer tip as a scribe on a piece of blued shim stock. The magnitudes of the runouts varied from less than 1/32-inch for Zones 9, 13, and 15 to nearly 1/16-inch for Zones 3 and 7. The 1/16-inch displacement on an effective tripod height of 2 inches indicated that the device was no more than 1.8 degrees off the true normal, assuming that the true normal lay within the figure traced. To further reduce this error, a 3/4-inch-base circle was selected for the tripod. Thus it was concluded that the 2-degree off-axis limit could be met by the normalizing device for all zones, regardless of the orientation of the 3 points on the surface.

Mounting for Inner Zones

Layout views of the mechanical portions of the system may be seen by referring to the full-size drawings in pockets at the end of the report. As shown on drawing 0001, the 8 inner transducer mounts for Zones 1 through 8 are supported on pads on a cruciform structure forming the base of the overall transducer support jig. As shown in the auxiliary views, the pads are angled in two directions to produce the orientations specified by the data of Table 2. An

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enlarged section of a transducer mount cartridge is shown in Figure 11.
The transducer proper is the 5/8-by 1-1/2-inch cylinder located on the
axis of the structure. A spherical tripod collar is attached to the
end of the transducer and rides in a cup which is free to slide in
the cartridge housing and is biased by a coil spring. The spherical
joint provides ± 5 degrees angular freedom for the
normalizer, and the sliding motion allows for $\pm$ 1/4-inch variation in
local helmet radius. The spring insures that 3-point contact is
maintained between the tripod and the helmet surface. An additional
function of the spherical joint is to insure that the effective pivot
point of the transducer is close to the helmet end. This helps to
reduce the relative sliding between the tripod legs and the helmet
surface as the tripod contacts the helmet surface.

Mounting for Outer Zones

As shown on drawing 0001, lower left, the transducer mounting
pads for the outer zones (9 through 16) are hinged in order to prevent
excessive wiping between the tripods and the helmet surface during
insertion of the helmet into the array. The hinged pads are rotated
by adjustable push rods suspended rigidly from the "lid" of the jig
to which the helmet is clamped. The push rods are adjusted so that
the tripods are pivoted into contact with the helmet surface during
the last few degrees of lid closure, the primary objective being to
provide a significant component of tripod velocity normal to the
helmet surface at the instant of contact. Once 3-point contact is
established in this manner, the small additional motion required to
translate the transducer tripod collar to its nominal position is not
expected to cause difficulty. The hinged pads for the outer transducers
are located around a ring-shaped piece which forms the top of the
cruciform structure supporting the inner transducers. The actuating
rods contact tabs extended from the hinged pads.

Figure 12 shows a full-scale view of the mounting cartridge
for the outer transducers. The case geometry is different from the
inner transducer cartridge, but the internal parts and principles of
operation are the same.

Helmet Mounting

Considerable thought was given to a simple means for mounting
the helmet in proper alignment on the hinged lid of the jig assembly.
Although this would not appear to be a major problem, some difficulty
arose due to the absence of flat surfaces or other reference marks on
the helmet shell as manufactured. It is not easy even to define a
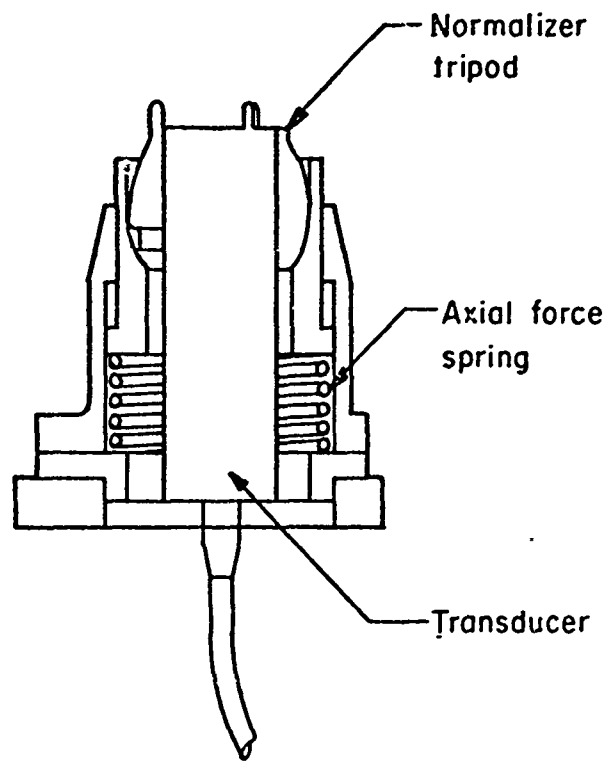scheme for accurately finding the plane of symmetry of a helmet,

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Figure 11. Transducer Mounting Cartridge for Inner Zones

Actuating rod
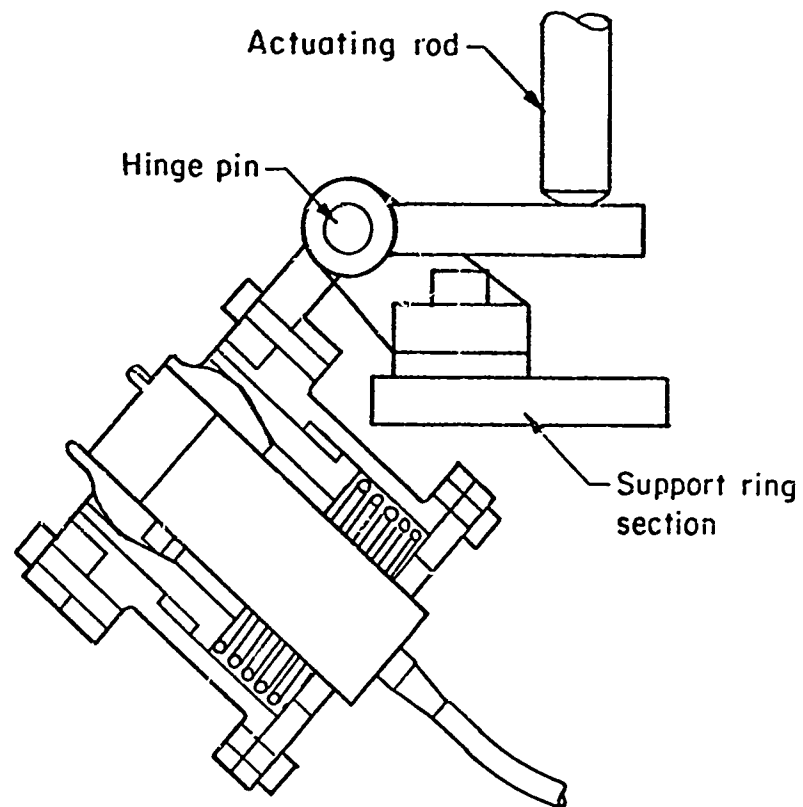
Hinge pin

Support ring
section

Figure 12. Transducer Mounting Cartridge for Outer Zones

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although it is evident that such a plane exists. It was decided to make use of the upper portion of the helmet for alignment, since proper orientation of the crown is of primary importance.

Alignment and Clamping

The alignment method adopted utilizes two sets of angled pads which contact the helmet about 2-1/4 inches from the bottom (base plane). The pairs of pads are in vee-form, and make use of the non-circular horizontal section of the helmet to provide preferential alignment.

In operation, one pair of pads, on the right in the layout views, is fixed and the other slides parallel to the long axis of the helmet (back-to-front axis). The sliding pads are moved in to exert a clamping force, and the helmet is rotated slightly until all four pads are in contact. It was determined graphically that when this condition is met, the helmet is properly aligned within about 2 degrees, which should be sufficiently accurate. The sliding pad piece is then clamped by two hand knobs, and two additional thumb screws at the front and back of the helmet are tightened to complete the mounting. The only function of the thumb screws is to prevent the helmet from falling away from the lid as the jig is closed.

It is quite possible that the transducer array will be inherently capable of providing alignment forces to the helmet without rigid clamping. If this is the case, the mounting system shown can be used with only minor modifications. The clamping devices would be provided with limit-stops so that the helmet would be free to slide into final position on the lid in response to the combined tripod spring forces. Since it is difficult to ascertain which method will work better without building a complete mockup, provisions have been made for both.

Lid Closure

The hinged lid which carries the helmet is shown in drawing 0002. The hinges are supported by the main jig structure so that all parts requiring critical alignment can be assembled as a unit. This construction will permit adjustment of the outer transducer actuating rods, as well as general checkout of the helmet-transducer interaction, to be made with the jig removed from the reservoir, i.e. with good access to all parts. The hingeline of the lid is approximately on a level with the ends of the actuating rods, so that sliding of the rods on their pads is minimized. The lid is counter-balanced for easy opening and closure. Final closure is effected by an adjustable lever clamp which stops the lid travel at a definite repeatable position.

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Reservoir Configuration

The reservoir for coupling fluid was designed as an essentially non-load-bearing housing surrounding the transducer jig and lid assembly. The reservoir assembly consists of 3 major portions: a main reservoir, a drip tray, and a sump area.

Main Reservoir and Drip Tray

The main reservoir tank surrounds the transducer jig and is filled to a level slightly above the uppermost transducer faces. A small centrifugal circulating pump continually supplies fluid to the tank from the storage area. The overflow runs over a weir notch and into the drip tray, which drains back to the sump. The drip tray serves both to collect the overflow and to catch the run-off from the helmet when the lid is opened to change helmets. The lid, fully opened, is supported horizontally over the drip tray and serves as a convenient work surface for helmet removal and clamping.

Sump

The sump, or sub-reservoir, is underneath the main tank. It serves as a source of makeup fluid, a collection point for weir spillage, and a location for the pump filter screen. All fluid routed from the sump to the main tank is filtered, and in this way the body of fluid in the transducer area is continually being cleaned. This feature was recommended by Branson Instruments personnel.

Ultrasonic Instrumentation

Two versions of the measuring system electronics are described below, each using the same mechanical jig and reservoir equipment. The full system provides for rapid printout of average thickness with no operator calculations or judgments. The simplified system is considerably slower and requires hand or calculator averaging, but is significantly less costly. Additional system levels between these extremes can be envisioned at intermediate costs.

Full System

The full system electronics would consist of 16 transducers, 16 Model 101 caliper circuits, averaging circuitry, a three-place

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digital voltmeter for visual readout of the average, a digital printer
for permanent record of the readout, and an oscilloscope for setup and
calibration purposes. As partially shown on the layouts, the lead
wires from the transducers would be run from the jig area up through
the fluid and gathered at two terminal blocks on the front and back
sides of the main reservoir tank. A dual cable would then be run from
the tank to a cabinet containing the caliper circuits, averaging
circuit, printer and voltmeter. Figure 13 shows an artist's conception
of the full system in operation. The incoming helmets are in the cart
at the right foreground, and inspected helmets are collected in the
cart at the rear. The operator works in a U-shaped area requiring a
minimum of walking, but still preserving separate stations for helmet
loading and unloading, readout, and record-keeping. With this system,
an operator should easily be able to inspect 80 helmets (the sample
size for lot) in less than an hour. This is to be compared with about
16 hours for the 16 helmets per lot inspected ballistically.

Simplified System

The simplified system would incorporate mechanical equipment
identical to the full system. However, only one caliper circuit would
be used, with a manual or automatic switching device interposed between
the transducers and the caliper circuit. The transducers would be
activated and the thickness read out and recorded at each zone in
sequence for subsequent averaging by calculator or by hand. The digital
voltmeter and oscilloscope would still be needed for readout and
calibration. It is estimated that 80 helmets could be inspected in about
2 hours with the simplified system.

SPECIFICATIONS

The design of an ultrasonic measuring system has been
carried to the layout stage, but not to the level of individual
component detail drawings. By definition, it is not possible to give
exhaustive specifications for a system that is still in an intermediate
design stage. On the other hand, an effort has been made to make the
drawings considerably more detailed than conventional layouts, and to
finish them almost to the degree afforded assembly drawings for a
completed design. The following sections cover the portions of the
system specification which have been at least tentatively defined at
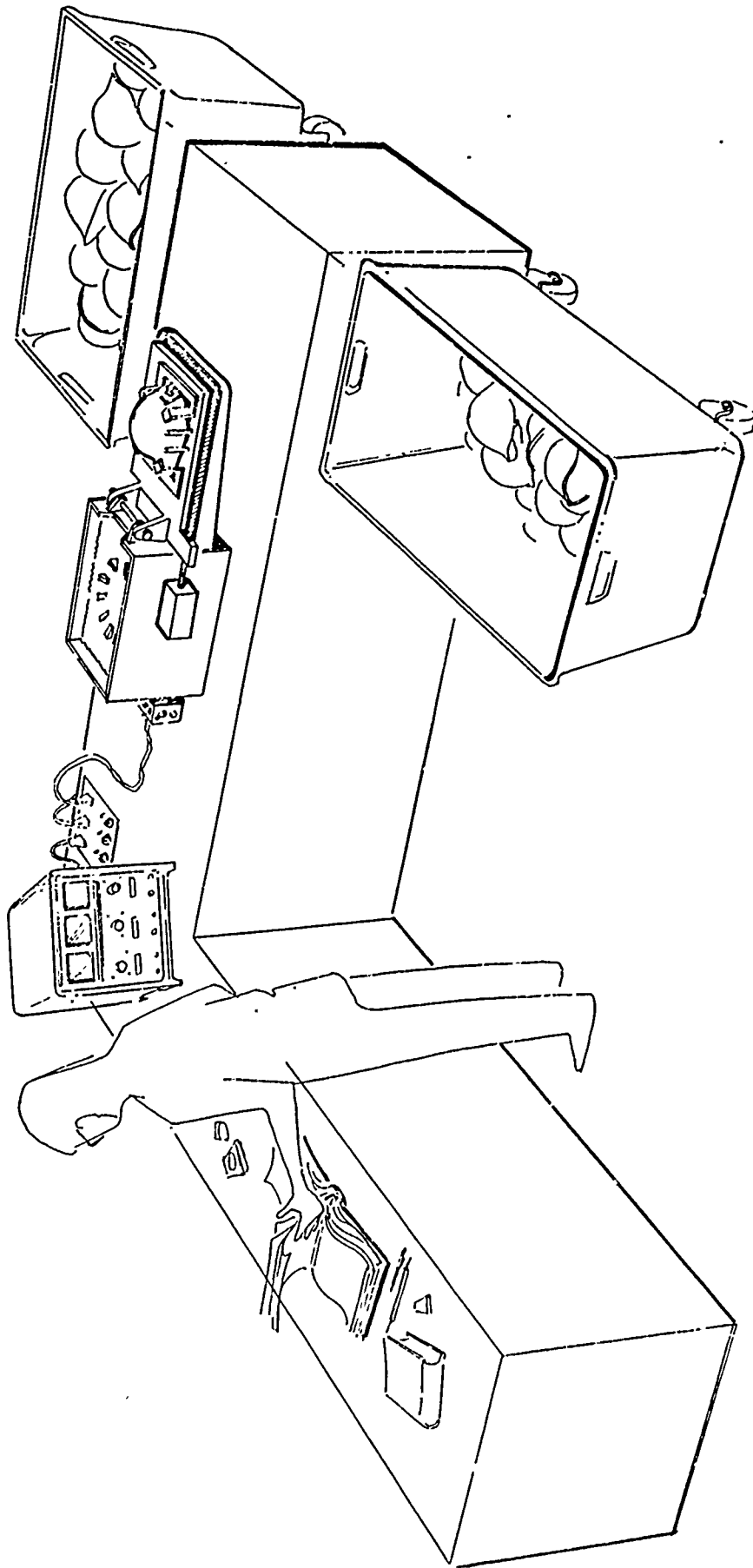the present level of development.

Figure 13. Overall View of Measuring System in Operation

Materials

The choice of materials for the jig and reservoir structures was based, generally, on considerations of strength, lightness, and corrosion resistance. Since it is likely that every part of the mechanical structure will come into contact with the coupling fluid at some time, the use of ferrous materials other than stainless steel has been avoided except where cost considerations are overriding, such as in the counterweight. The following is a listing of tentative materials specifications, by sub-assembly.

1. Transducer Support Jig. Includes bottom mounting ring, upper mounting ring for outer transducers, and cruciform support assembly for inner transducers: Aluminum Weldment.

2. Transducer Mounting Pads: Aluminum

3. Transducer Cartridges: Stainless Steel.

4. Hinge Pins and Fasteners: Stainless Steel.

5. Counterweight: Hot rolled steel, painted or plated for corrosion resistance.

6. Counterweight Rod: Stainless Steel.

7. Lid Assembly. Includes helmet positioning pads and clamp brackets: Aluminum.

8. Reservoir: Aluminum weldment.

9. Drip Tray: Aluminum.

10. Main Lid Hinge and Latch Brackets: Aluminum.

Purchased Items

The purchased items specification is divided into two groups, those for the mechanical jig and reservoir assemblies and those comprising the ultrasonic instrumentation. Fasteners are omitted.

Jig and Reservoir Assemblies

	Description	Quantity
1.	Pump, circulating, centrifugal, Teel submersible, 150 gph (W. W. Grainger Stock No. 1P680) or equivalent	1
2.	Screen, filter, 40 mesh (W. W. Grainger Stock No. 1P739) or equivalent	1
3.	Knob, hand, Jergens HK-4-C-A or equivalent	2
4.	Latch, adjustable, De-Sta-Co Model 351 or equivalent.	1

Ultrasonic Instrumentation (Full System)

	Description	Quantity
1.	Transducer, ultrasonic 5/8-inches O.D. by 1-1/2-inches long with 24-inch lead wire	16
2.	Caliper circuit, Sonoray Model 101	16
3.	Video output scope (for calibration)	1
4.	3-place digital voltmeter with over-range indicator	1
5.	Digital printer	1
6.	Averaging circuit for 16 channels.	1

Costs

The following data are intended to give an approximate cost picture for the helmet measuring system. The cost for the ultrasonic equipment is based on a quotation made in March of 1969, and would be subject to confirmation by Branson Instruments. The cost estimate for constructing the mechanical portion of the system is based on the layouts only, and cannot be as accurate as one made from detail drawings.

Ultrasonic Equipment

For the full system, as described above	$24,000
For the simplified system (manual switching and averaging)	$7,000 - $8,000

Jig and Reservoir Assemblies

For completion of detail drawings	$2,500 - $3,500
For fabrication only	$2,500 - $3,000

Thus, it is estimated that a first prototype of the "full system" would cost between $29,000 and $32,000.

As with any developmental system, additional research time would be required for revisions, initial setup and calibration, and testing of the prototype. These aspects of the development are not included in the above estimate.

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the Phase II effort, it is concluded that a thickness measuring system utilizing available ultrasonic instrumentation offers a practical means for implementing thickness inspection for M-1 helmets. Although the system is considerably more complex than the single mechanical caliper currently in use, it is capable of making rapid, simultaneous, multiple measurements without the need for operator adjustments or judgments.

It is recommended that system development be continued in a Phase III effort to include preparation of detail drawings and the construction, calibration, and testing of a prototype system.

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Preliminary Design of a Thickness Inspection System

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13. ABSTRACT

Previous studies demonstrated that the currently used ballistic
inspection of M-1 helmets could be replaced by an inspection based on thickness
requirements. The objective of the current study was to identify the most
effective way to perform the inspection in production situations, and to make
a preliminary design of a thickness inspection system.

Several thickness-measuring methods were evaluated. Consideration
was given to ultrasonics, electromechanical and pneumomechanical devices,
radiological methods, and eddy current methods. Approaches based on both
averaging and minimum seeking systems were considered. The evaluations were
aided by brief engineering studies and by discussions with instrument manu-
facturers. The eight most promising systems were considered in some detail,
and for these, schematic designs were developed. A comprehensive rating
chart was used to aid in making a final selection. Factors considered in the
selection process included potential accuracy, jig complexity, commercial
availability of components, speed of operation, operator hazards, and overall
reliability. Based on these considerations, a thickness-averaging ultrasonic
system, containing a set of stationary transducers connected to averaging
circuitry and digital readout, was selected as most appropriate. A design of
such an inspection system was prepared.

14. KEY WORDS	LINK A		LINK B		LINK C	
	ROLE	WT	ROLE	WT	ROLE	WT
Inspection	8		9,4			
Systems	8		9			
Thickness	9		4			
Helmets	9		4			
Design			8			
Ultrasonic tests			10			