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TRANSFORMATION OF THE COORDINATES FROM ONE GAUSS-  
KRÜGER MERIDIAN ZONE TO THE NEIGHBORING ZONE,  
USING THE BULL ELECTRONIC COMPUTER "GAMMA 3 B"

by K. Naser

- East Germany -

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TRANSFORMATION OF THE COORDINATES FROM ONE GAUSS-KRÜGER MERIDIAN ZONE TO THE NEIGHBORING ZONE, USING THE BULL-ELECTRONIC COMPUTER "GAMMA 3B"

Following is the translation of an article by K. Näser entitled "Koordinatenumformung von einem Gauss-Krüger-Meridianstreifen in den benachbarten mit Hilfe des Bull-Elektronenrechners "Gamma 3 B" (English version above) in Vermessungstechnik, Vol 8, No. 3, Mar 60, Leipzig, pages 58-62.7

General

The mapping of the DDR\*) for the topographic maps in scales from 1:500,000 to 1:5000 is accomplished by the projection of meridional zones of 6° width, while in the DDR the meridional zones with the mean meridians of 9° and 15° east of Greenwich are used. A part of the existing field of reference points was until now coordinated only in the 4th meridional zone with the mid meridian 12° east of Greenwich. It became necessary, therefore, to determine for this part of the Gauss-Krüger coordinates in the meridional zones with the mean meridian 9° and 15° east of Greenwich so that the trigonometric field of reference points can be used as a basis for the mapping of the country.

The transformation from the 4th meridional zone to the two neighboring zones was performed according to the affine transformation method on the reference ellipsoid having the Krassovski dimensions.

The reference points of I. to III. order on the border meridian (the meridian 12° east of Greenwich) of the two 6° wide meridional zones were coordinated with 0.5° overlap on both sides; the reference points of IV. order were coordinated with an overlap of 0.25°. Consequently,

\*) T.N.: German Democratic Republic

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the formidable task arose to transform 35,000 pairs of coordinates from the 4th meridian strip to the neighboring ones.

Only modern computing machines could perform this veritable mass calculation speedily and economically. Even the affinitive transformation was done with punched card machines. As a result, the basic values for the transformation to the neighboring meridional zones were available in the form of punched cards. A modern electronic computer of French origin, the Bull Electronic Computer "Gamma 3 B", was used for the calculations.

Punched Card Machines

The following punched card machines were used for the transformation work:

Bull Card duplicator  
Bull Electronic Computer "Gamma 3 B"  
Rheinmetall Sorting machines  
Bull Tabulating machines

The reference 2) in the bibliography describes the operation of the conventional punched card machines, sufficient for the understanding of what follows. The electronic computer "Gamma 3 B" will now be briefly described.

The French firm Bull developed an electronic computer which is fed the data to be processed by means of a punched card machine and which in turn feeds the computed results to the same punched card machine. The input data is always in the form of punched cards. The output or the result is accomplished

by combining the computer with the Bull card duplicator, and delivering punched cards, or  
by combining the computer with the Bull tabulating machine, delivering a list. It is also possible by a further combination of the tabulating machine with a sum stenciler, to receive the results in the shape of punched cards.

Fig. 1 shows the schematic of the electronic computer. The punched card data are scanned, column by column, by the adjoining machine, the Bull card duplicator or the

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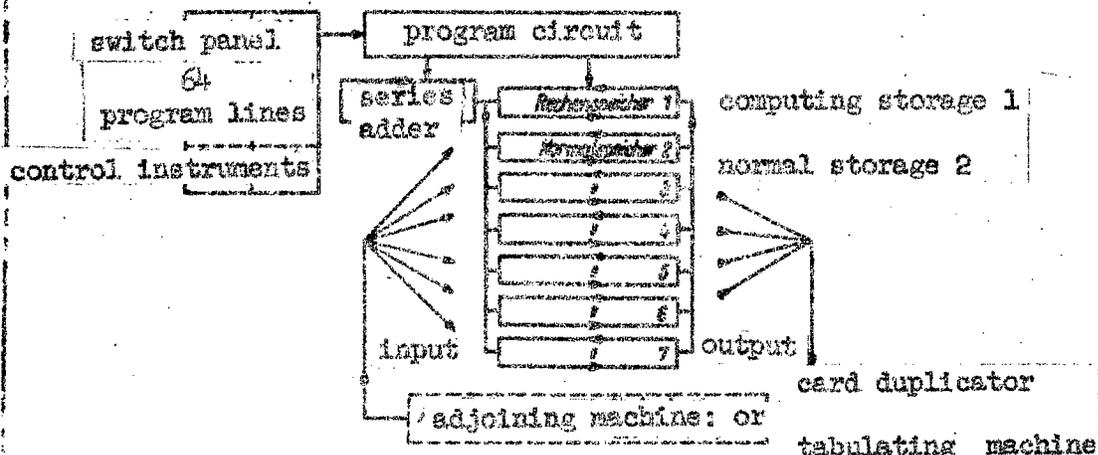


Fig. 1. Schematic of the Bull electronic computer "Gamma 3 B"

Bull tabulating machine. Each punched hole generates in the moment it passes beneath the selector brush an electric impulse which is transmitted to the computer over a cable strand. The computer and the adjoining machines operate synchronously so that any data of a column can be transmitted to the dual system when the intelligence is fed to the normal storage.

The storage is accomplished kinematically through series of pulses which circulate on an electric conductor and are amplified and controlled by tubes. Each memory storage has a capacity of 12 decimal places which corresponds to an impulse series of 48 impulse points. (Fig. 2) The normal memory serves only for the storage of information. There is no limitation on the splitting of the 12 storage points, i.e., the storage drum can receive several values provided that the total number of decimal places does not exceed 12. Only the pertinent storage points are then called upon to perform the elementary calculation operations.

impulse series

splitting

representation in numerals

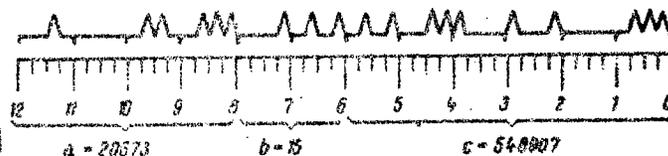


Fig. 2. Impulse series in a storage of the electronic

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This electronic computer is a one-address machine, i.e., all elementary calculating operations can be performed only by way of one storage, viz., the computing stage. The computing storage differs from the normal storages insofar as a series-adding device is contained in its circuit. The series-adding device is able to perform addition, subtraction, multiplication (repeated addition) and division (repeated subtraction) of the storage contents with the contents of a section of the normal storage which is selected through a command. These operations are performed in the semibinary system. If an increase in the capacity of the computing storage is desired, an operational command can connect the normal storage 2 with the computing storage. The computing accuracy of multiplication and division can thus be increased. The following number of places (in the decimal system) result for the arithmetic operations:

Addition:	summands each of	11 places
Subtraction:	minuend and subtrahend each	11 places
Multiplication:	multiplieand	11 places
	multiplier	12 places
	product	23 places
Division:	dividend	23 places
	divisor	11 places
	quotient	12 places

The commands are controlled by the program circuit. The sequence of the functions of the machine takes place according to the program lines of the control panel. Each line of the program corresponds to an elementary operation. These elementary operations are: the arithmetical operations, the transmittal of the normal storage contents to the computing storage and from the computing storage to one of the normal storages, the erasing of storage contents, the comparison of the computing storage contents with the contents of a normal storage, the transfer of the computing storage contents and the conditional as well as the unconditional shifting commands from one program line to the other.

One program line comprises 4 informations which are energized by the impulse distributor on the switch panel over cable connections to the corresponding 4 boxes:

Type of operation: designates the operation to be performed due to the program line;  
Address: designates the called-for storage;

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Begin and end  
of command: designates the spots on the storage  
which are called for for the operation  
with the computing storage.

Three program lines are necessary, on the average, for the performance of an arithmetical operation, including the transfers.

In the standard type of the electronic computer "Gamma" a program may contain up to 64 program lines. The 64 elementary operations are performed with the velocity of electron travel, needing practically no time at all. Thus, the speed of the electronic computer is determined only by the capacity of the adjoining machine. The efficiency of the Bull card duplicator is about 6000/hour and of the Bull tabulating machine, depending upon the number of intermediate functions, up to 9000 cards/hour.

The sequence of the run of the individual program lines can be changed conditionally or unconditionally by operational commands. It is thereby possible to choose program steps depending upon given conditions, or certain program sections can often be repeated arbitrarily. It is also possible to have an additional control of the program run by employing 16 control switches, 16 command controls, 8 relay variations and 8 selector controls.

In order to try out and test a program, it is possible to run each program step separately and inspect the storage contents with an oscillograph.

The standard model of the electronic computer can be supplied with an automatic determination of the plus or minus signs. This is particularly important for technical calculations as, for instance, in surveying work and geodesy. If this accessory is not provided, as was the case with the computer at our disposal, the sign of the result can be determined by comparing operations. But this calls for additional program lines. Another way is to try and plan the program so that the signs of the individual results can be determined beforehand through a presorting of the data material. This second way was chosen by us.

We had the use of the standard model of the elec-

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tronic computer "Gamma 3 B". Its capacity is expressed in the code number 764-64. This means that "Gamma 3 B" is equipped with:

- 7 storages (1 computing, 6 normal storages)
- 6 input organs
- 4 output organs
- 64 program lines

An increase in its capacity is possible based on the building block principle.

In its biggest model, the computer has 61 storages, 6 input organs, 4 output organs and a program capacity of 128 program lines. It is then suitable for scientific computations for which purpose an additional program card control is provided.

All the circuitry components (the kinematic storage principle requires relatively few electron tubes --about 400) are placed in a closed cabinet with the overall dimensions of 1.5 x 1.6 x 0.7 meters. This cabinet is connected by a flexible cable with the adjoining machine. The weight of a standard computer is about 850 kilograms.

Transformation Formulae and General Organization

Generally speaking, formulae with constant coefficients are especially suited for manipulation with punched card machines, because the constants are fed only once by a lead card into the machine.

Transformation Formulae

For the transformation from one Gauss-Krüger system into the neighboring one, the following formulae have been devised by Hristow 3). They are especially useful from the point of view of punched card techniques.

1st system:  $x, y$                       2nd system:  $x', y'$

An auxiliary point  $P_0$  is coordinated with  $x_0$  and  $y_0$  and with  $x'_0$  and  $y'_0$  in both systems.

$$\begin{aligned} \Delta y &= y - y_0 & x &= x'_0 + K_{11} \Delta x - K_{12} \Delta y + K_{21} \Delta x^2 - 2K_{22} \Delta x \Delta y \\ \Delta x &= x - x_0 & &- K_{11} \Delta y^2 + K_{21} \Delta x^2 - 3K_{22} \Delta x^2 \Delta y - 3K_{31} \Delta x \Delta y^2 \\ & & &+ K_{32} \Delta y^2 + \text{terms up of 4th order} \end{aligned}$$

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$$\begin{aligned}
 x' &= x_0' + K_{12} \cdot 1x + K_{21} \cdot 1y + K_{21} \cdot 1x^2 + 2K_{22} \cdot 1x \cdot 1y \\
 &\quad + K_{22} \cdot 1y^2 + K_{22} \cdot 1x^3 + 3K_{23} \cdot 1x^2 \cdot 1y - 3K_{22} \cdot 1x \cdot 1y^2 \\
 &\quad + K_{21} \cdot 1y^3 + \text{terms up of 4th order} \quad (1)
 \end{aligned}$$

The transformation formulae of Hristow are derived from an expansion in a series with the auxiliary point  $P_0$  as the zero point of calculation.

$K_{11}$ ,  $K_{12}$ ,  $K_{21}$ ,  $K_{22}$ ,  $K_{31}$ ,  $K_{32}$ ,  $X_0$ ,  $Y_0$ ,  $X'_0$  and  $Y'_0$  are constant coefficients, which are determined by the position of the auxiliary point and the distance of the median meridians of both systems. Hristow supplies in 3) formulae for the coefficients for arbitrary positions of the auxiliary point and three particular auxiliary points:

- Auxiliary point on the mid meridian of the first system;
- Auxiliary point on the mid meridian of the second system;
- Auxiliary point on the boundary meridian between the 1st and 2nd system.

If the auxiliary point is chosen so that  $|\Delta y| \leq 100$  km and  $|\Delta x| \leq 70$  km then the terms of 4th and higher power can be neglected to achieve a transformation accuracy in the coordinate directions of  $\pm 0.01$  m.

The formulae (1) are still not very well suited for punched card computing due to the large number of individual terms and the necessity for the plus or minus sign determination for each term. Gotthardt gives in 4) a rearrangement of these equation groups, which he uses for his calculations by means of the "Brunsviga 183".

$$\begin{aligned}
 x' &= x_0' + \Delta x(K_{11} + \Delta x(K_{21} + \Delta x K_{21} - \Delta y K_{22}) \\
 &\quad - \Delta y(K_{22} + \Delta y K_{21} + \Delta x K_{22})) \\
 &\quad - \Delta y(K_{12} + \Delta y(K_{21} + \Delta x K_{21} - \Delta y K_{22}) \\
 &\quad + \Delta x(K_{22} + \Delta y K_{21} + \Delta x K_{22})) \\
 y' &= y_0' + \Delta y(K_{11} + \Delta x(K_{21} + \Delta x K_{21} - \Delta y K_{22}) \\
 &\quad - \Delta y(K_{22} + \Delta y K_{21} + \Delta x K_{22})) \\
 &\quad + \Delta x(K_{12} + \Delta y(K_{21} + \Delta x K_{21} - \Delta y K_{22}) \\
 &\quad + \Delta x(K_{22} + \Delta y K_{21} + \Delta x K_{22})) \quad (2)
 \end{aligned}$$

Introducing new auxiliary notations which are different from those used here, Gotthardt shows in 4) also the next grouping, which we reproduce here, but already modi-

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fied for punched card program on "Gamma 3 B":

$$\begin{aligned}
 \text{(I)} \quad & \Delta x = x - x_0 & B &= x_0' + \Delta x \\
 & \Delta y = y - y_0 & A &= y_0' + \Delta y \\
 \text{(II)} \quad & a = K_{11} & + \Delta x K_{21} + \Delta y K_{31} \\
 & b = K_{21} & + \Delta x K_{31} - \Delta y K_{32} \\
 & c = K_{12} & + \Delta x a + \Delta y b \\
 & d = (K_{11} - 1) + \Delta x b & - \Delta y a \\
 \text{(III)} \quad & x' = B + \Delta x d - \Delta y c \\
 & y' = A + \Delta x c + \Delta y d.
 \end{aligned} \tag{3}$$

The calculation is performed in these three steps by one run each of the cards through the Bull card duplicator with attached computer "Gamma 3 B".

Selection of the Auxiliary Points and Division of the Regions of Transformation

The points to be transformed lie on both sides of the 12° meridian in the zone  $11^\circ \leq L \leq 13^\circ$ . If the auxiliary point is put onto the mid meridian of the first system, of the fourth meridian zone, then  $|\Delta y| \leq 100$  km is for the territory of the German Democratic Republic, with the exception of a small region in the South of the German Democratic Republic which contains about 120 reference points. The auxiliary points are distributed 30' of latitude apart on the 12° meridian. (See Fig. 3.) Thus 9 horizontal transformation zones are formed, numbered from 0 to 8. In each zone transformations, two directions are possible which are called transformation cases:

Transformation case 1 = Transformation from the 4th to the 5th meridian zone;

Transformation case 2 = transformation from the 4th to the 3rd meridian zone.

In addition, for each transformation case, there are two possibilities for the position of the fixed point, viz., east or west from the mid meridian.

This grading leads to 32 transformation regions which are named according to their transformation zone, the transformation case and the sign of  $\Delta y$  (positive = 1, negative = 2). Disregarding the curvature of the circles of latitude, a transformation region contains the fixed

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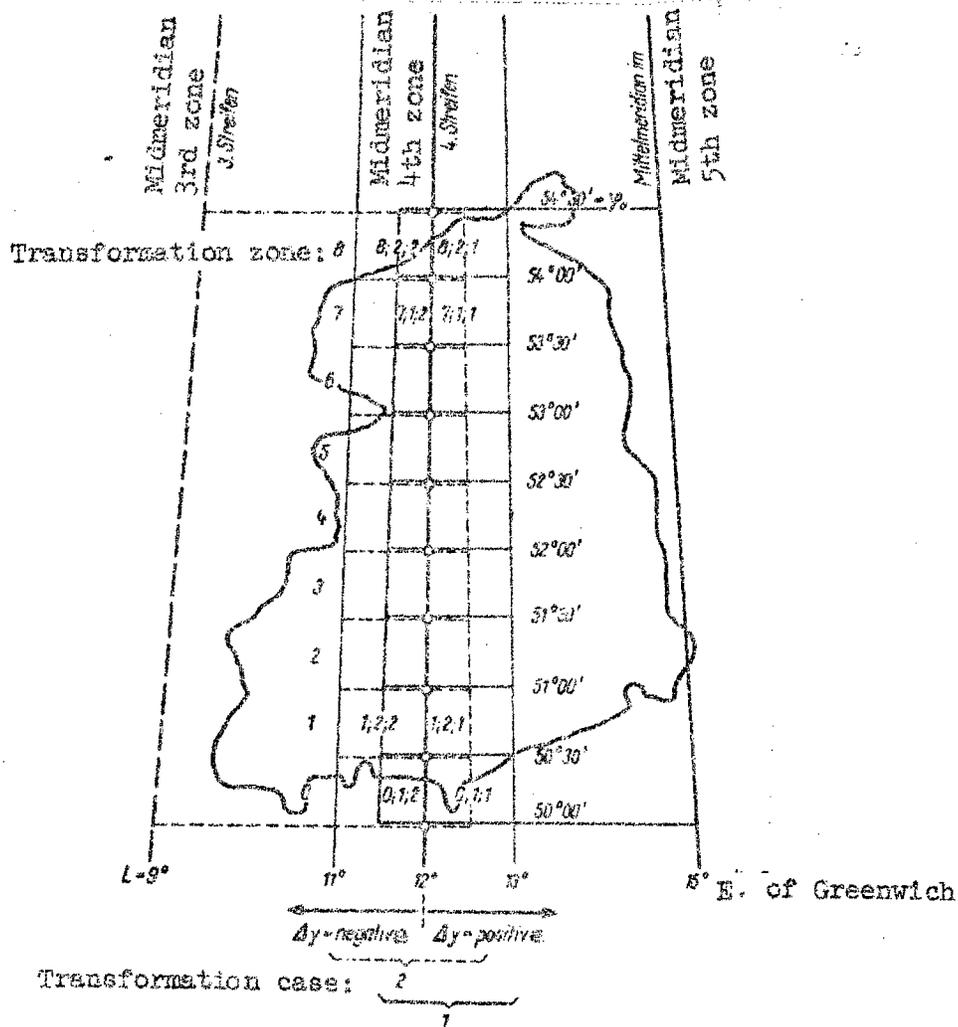


Fig. 3. Division in transformation regions.

points of 24 (or 48) sheets of the topographic map 1:25,000. The number of coordinate pairs in one transformation region varies between 200 and 3000.

Transformation Constants

The computation of the transformation constants ( $K_{11}$  - 1),  $K_{12}$ ,  $K_{21}$ ,  $K_{22}$ ,  $K_{31}$  and  $K_{32}$  is done according to the formulae given by Hristow in 3) and referred to the ellipsoid of Krassowski.  $x_0$  was taken from 5) while  $x'_0$  and  $y'_0$  are taken from the table 6).

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Check of the Transformation

In order to check the results of the transformation thoroughly, each coordinate pair is first transformed with the south auxiliary point and in a second calculation by means of the north auxiliary point. Only after the two results are compared, the result of the second calculation is tabulated. The permissible limit for the discrepancy between both results is established with  $\pm 0.01$  m.

The Punched Card Program

The original data are contained in the punched cards resulting from the affinitive transformation. They carry as a defining characteristic the old serial number and the number of the old map scale table sheet which defines each coordinated point unambiguously as well as the coded number of the new 1:25,000 sheet which enables one to coordinate each point mechanically on the new map. The resulting cards of the affinitive transformation carry as punched data the Gauss-Krüger coordinates in the 4th meridian zone on the Krassowski ellipsoid and in the system of the new grid of 1st order. The operational cards which serve for the computation of the coordinates in the neighboring meridian strips must contain, in addition, (for programming reasons) the designation of the region of transformation and a card number, because the computation affects several operational cards. The initial cards are employed to this purpose, through a duplicating process, for the transformation with the south auxiliary point, as operational cards 1 and, through a second duplicating process, for the transformation with the north auxiliary point, as operational cards 4. The region of transformation and the card number are punched during the duplicator runs, energized by impulse distributors. The gathering of the cards according to transformation zones takes place during the duplication since the cards of the affinitive transformation are arranged according to the new 1:25,000 sheets.

a.) Computation of  $x'_s$  and  $y'_s$  with the south auxiliary point.

1. Computation of  $\Delta x$ ,  $\Delta y$  and B.A.

During a run through the duplicator, the electronic

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computer calculates  $x$  and  $y$  simultaneously and  $B$  and  $A$ , in view of the subsequent adjustment according to the formulae

$$B = z'_0 \pm |\Delta z|$$

$$A = y'_0 \pm |\Delta y|$$

The change of the computing program, addition or subtraction of the amount of the coordinate differences, is done by switch changes according to the designation of the regions of transformation.  $B$ ,  $A$  and  $\Delta x$ ,  $\Delta y$  are punched into the operational card 1 by the duplicator.

2. Adjustment of  $B$  and  $A$ .

The compilation of the transformation zones took place according to the sheet arrangement of the topographic map of scale 1:25,000. But this procedure is not quite exact due to the curvature of the circles of latitude. In addition, the graphically accomplished insertion of the coordinate pairs into the new map sheet is somewhat uncertain. For these reasons, a special adjustment of the computing step 1 is performed. Two "null checks" are performed in a run of the operating cards 1 through the Bull tabulating machine:

$$x'_0 - x_0 + x - B = 0$$

$$y'_0 - y_0 + y - A = 0$$

Discrepancies in these checks uncover errors in the computation and positioning errors in the regions of transformation. These errors are rectified by a replacement of the faulty punched cards and a re-run.

3. Computation of  $c$  and  $d$ .

The intermediate results  $c$  and  $d$  are determined in a card run through the Bull card duplicator with adjoined electronic computer. The operational cards 1 run through the scanner of the duplicator, while a new set of cards, the operational cards 2, goes through the punching device. The determining holes of the operational cards are duplicated onto the cards 1 and, in addition,  $\Delta y$  and  $\Delta x$  are punched in, as well as  $c$  and  $d$ , which are supplied by the computer.

All these processes for programming could be performed without regard to plus or minus signs because it is as-

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certained, through the particular selection of the range of the transformation regions, that the products in the formulae (3.II) are always smaller than the values of the constants  $K_{22}$ ,  $K_{21}$ ,  $K_{12}$  and  $(K_{11}-1)$ . It is always the case that  $a$  has the same sign as  $K_{22}$ ,  $b$  as  $K_{21}$ ,  $c$  as  $K_{12}$  and  $d$  as  $(K_{11}-1)$ . These considerations make it possible to combine the computation of  $c$  and  $d$  in a program of the electronic computer "Gamma 3 B" which is governed by means of the operational cards only by the type of the transformation case. The signs of  $c$  and  $d$  are recorded on the operational cards 2 because they are still needed for the subsequent sequence 4 of the operation.

$\Delta x$  and  $\Delta y$  are fed into the electronic computer (for multiplication purposes) always with their full value to within 0.001 m. This specification in no way slows the program, due to the speed of electronics. On the other hand, the programming is thereby simplified.

4. Calculation of  $x'_s$  and  $y'_s$ .

In the 4th run through the duplicator with adjoining electronic computer, the first computation of  $x'$  and  $y'$  is finished. The result of the transformation with the south auxiliary point  $x'_s$  and  $y'_s$  is punched into a third set of cards named "result cards 3". At the same time, the designating characteristics are punched into them by the duplicating machine.

The programming for the electronic computer is similar to half a step of card run 3 because the computation formulae are of a similar structure. The storage capacity of the "Gamma 3 B" is thereby fully utilized due to the larger number of places in the factors, but only about half of the available program lines are used. The program lines which thus remain unused are taken advantage of for a complete plus or minus sign control and no change of the control panel is necessary during the run of all transformation zones.

b.) Calculation of  $x'_n$  and  $y'_n$  with the north auxiliary point.

5. to 7.

The program steps of punched cards for the computation of  $c$  and  $d$  are the same as stated in sub 1. and 3. for

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the calculation with the south auxiliary point. The starting material is provided by the cards 4. c and d are punched into the cards 5.

8. Sorting of the operational cards 5 parallel to the result cards 3.

The step following this one requires that the operational cards 5 and the result cards 3 be presented in two sets arranged parallel to each other. The sorting of both sets is done together according to the non-ambiguous order characteristics. Under the given circumstances a sorting of both card sets is necessary based on 11 columns.

9. Computation of  $x'_n$  and  $y'_n$  and preliminary comparison with  $x'_s$  and  $y'_s$ .

We start off with the operational cards 5 and find the transformation results with the north auxiliary point in the same way as in step 4 of the punched card program. These results are punched into the result cards 3. At the same time,  $x'_n$  and  $y'_n$  are compared with  $x'_s$  and  $y'_s$ .

The operational cards 5 are scanned in the card duplicator for c, d,  $\Delta y$  and  $\Delta x$ , B and A, and the information transmitted to the electronic computer. At the same time, a first comparison is made in the duplicator of the characteristics of the result cards 3 which run through the punching device of the duplicator. Thus, the parallel run is checked even before the results are punched in so as to avoid an erroneous punching of cards which do not belong to one another.

In the second part of the card run  $x'_n$  and  $y'_n$  are determined in the computer, delivered to the punching device and punched into the result cards. Then, in the third part of the run, two comparisons are made.

The second comparison in this card run compares the results of the transformations of the south auxiliary point with those of the north auxiliary point. Both are punched into the result cards 3 and are compared to within 1 m only. A finer comparison is not practical for the following reasons: if the difference between the two results --albeit within the accuracy of computation-- is transmitted with all the decimals, all too often a dis-

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crepancy in the comparison would appear which would impede a steady operation of the machine.

In the third comparison, the characteristics of both cards are once more compared in order to uncover punching errors due to the punching head, which could result in missing punch marks. If the comparison fails, the duplicator stops automatically. The faulty card is then eliminated.

10. Sorting of the result cards 3 for listing.

The listing of the result cards 3 is meant to form the basis for the establishment of the new card file of the fixed reference points. The sequence for the listing of the fixed points in the new card file for these points is established by sorting of the punched cards according to the following criteria:

- 1.) According to the origin of the coordinate system (in the regions of the old country boundaries the coordinates are separated according to their belonging to the previous country triangulations);
- 2.) In the order of decreasing values;
- 3.) According to the point arrangement;
- 4.) According to the sheets of the new 1:25,000 topographic map.

11. First tabulations of the results of the transformations and final adjustment.

The Bull tabulating machine writes first lists which contain the results of the transformation computed with the north auxiliary point. The characteristics are also listed. These first tabulated sheets serve as the basis for the establishment of the new card file for the fixed points. The coordinated pairs are thereby put in the proper order in the preceding card program step in a form suitable for the card file.

Simultaneously with this tabulation, the final adjustment takes place, a comparison of the transformation results with the north and the south auxiliary point. The tabulating machine computes the quantities  $|dx| = x's - x'n$  and  $|dy| = y's - y'n$  and prints them in the list. The transformation is considered in error if  $|dx|$  or  $|dy|$  exceeds 10 mm.

The computation of the adjustment differences d slows

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the output of the Bull tabulating machine down to about 2500 cards per hour because of the necessity for four intermediate runs.

12. Second tabulation of the results of the transformation.

In order to eliminate errors completely in the tabulation, the result cards are once more listed with another Bull tabulating machine. The thus created second table is used as a check for the establishment of the new card file of the fixed points.

Here no adjustment takes place, so that the machine can be operated at an output of 9000 cards per hour.

Frequency of Errors

The frequency of errors in the program run as described just now was investigated, based on the results of the adjustments in the ninth and the eleventh step of the punched card program. These errors could only have been caused in the card punching machines during the programming steps 3, 4, 7 and 9, because the other steps of the program are checked individually.

Six discrepancies for 1000 transformations were found on the average for these 4 runs through the Bull duplicator with adjoining electronic computer. This corresponds to 1.5% miscalculations per run.

The reasons for these errors are to be found mainly in the adjoining machine, the Bull card duplicator, and mostly in the mechanical part of the card transport and the punching head. Cards not fed in quite straight resulted in erroneous scanning beneath the scanning brushes. The punching head of the duplicator functioned not quite faultlessly and in some cases it punched in wrong values, although the computer had delivered the correct results. Sometimes, it omitted one or more punched holes. The reason for a minor part of the miscalculations can be attributed to the way the electronic computer operates. If the warm up period of the computer was not adhered to strictly before the start of the operations, wrong results could ensue.

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Time Requirements

It was not necessary, in the present case, to prepare the initial cards by manual punching for the transformation. The times for the preparation of the operational cards 1 and 4, as well as for their checking, are, therefore, omitted in the following considerations. At most, they correspond to the time required for the copying of the original coordinates onto a form and, in the case of manual transformation, for collating.

The final output can be set at about 270 transformations per hour. This goes for the punched card transformation with independent second computation, mechanical comparison of both transformation results, sorting of the result cards and listing, if the programming is done in the way described above. This number was arrived at from the technical capacity of the employed card punching machines. In practice --including programming and program checking-- only about a third of the technically possible output was achieved: 90 transformations per hour.

Compared with this, the output of a human computer who performs the transformations manually by means of tables or who uses the Hristow transformation equations on an automatic electrical calculating machine is only 2 to 3 transformations per hour.

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the transformation of meridian zones of  $3^\circ$  and  $6^\circ$  width,  
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