Nov. 12, 1940. H. C. GOODRICH 2,221,476

SLIDE RULE

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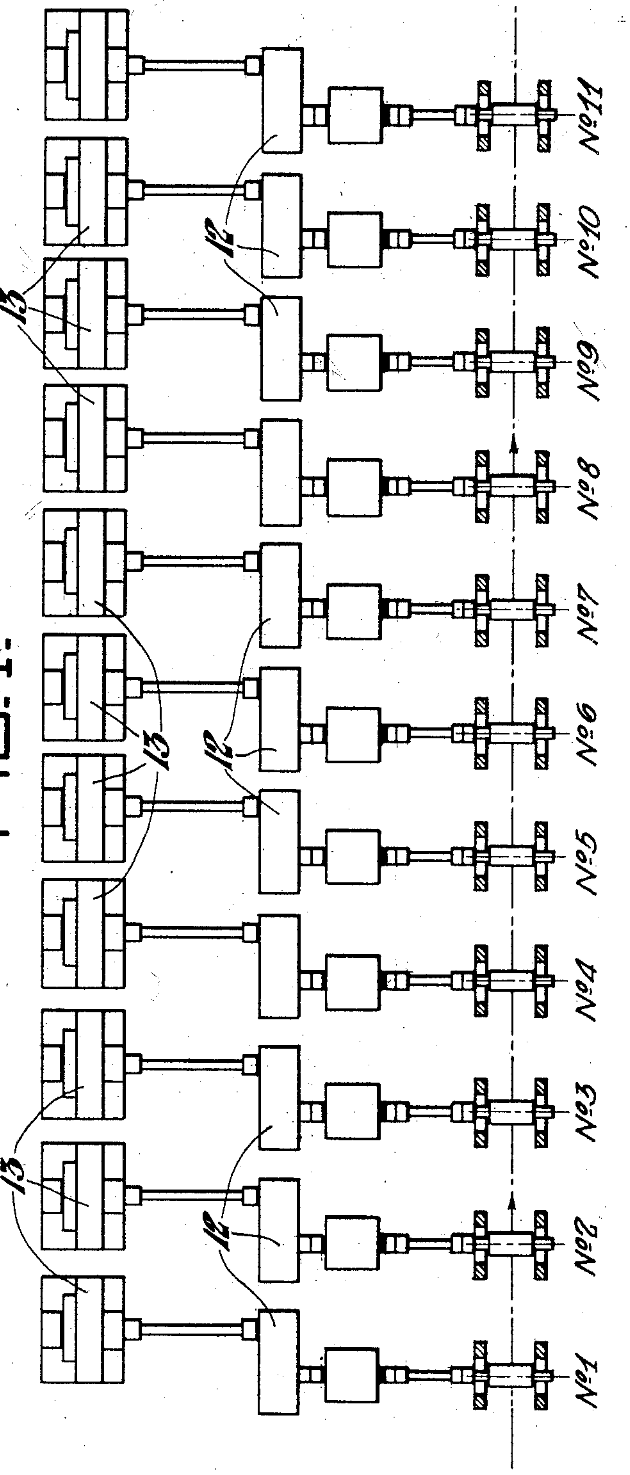

FIG. 1.

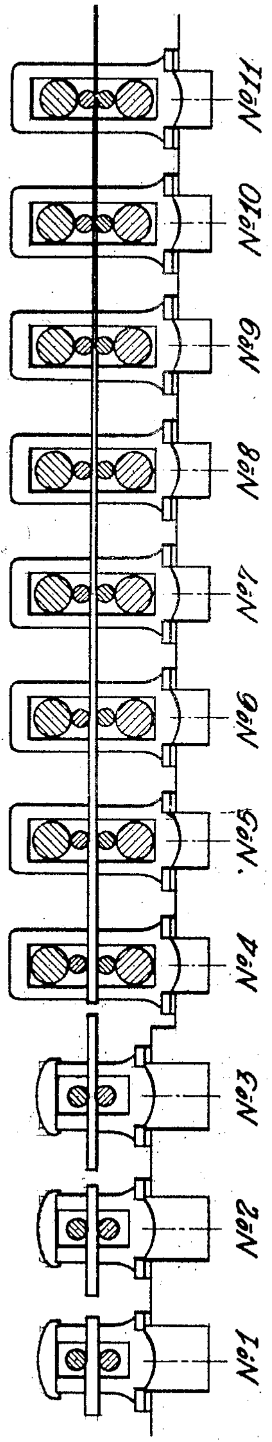

FIG. 2.

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SLIDE RULE

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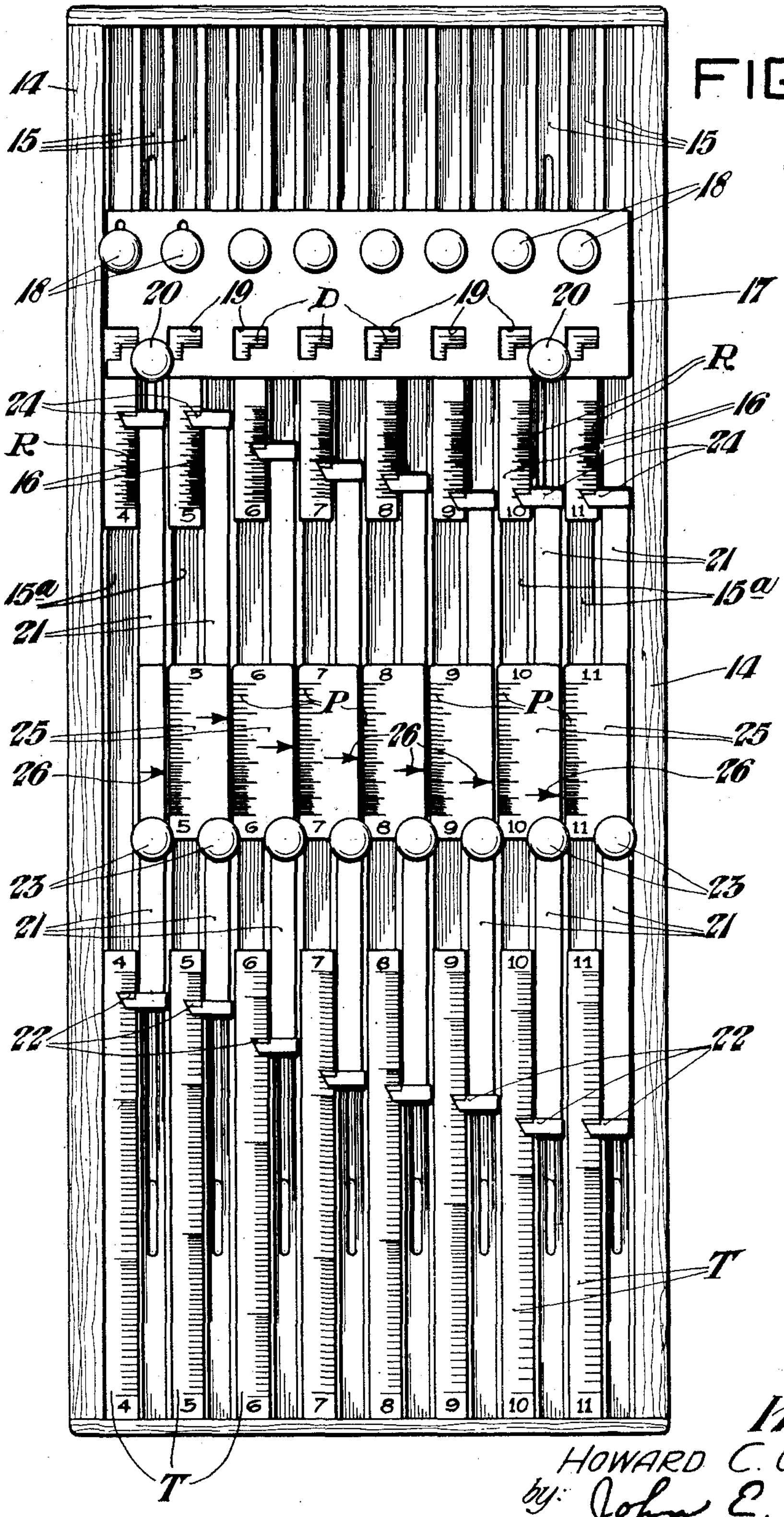
FIG. 3.



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SLIDE RULE

Filed Nov. 9, 1939 6 Sheets-Sheet 3

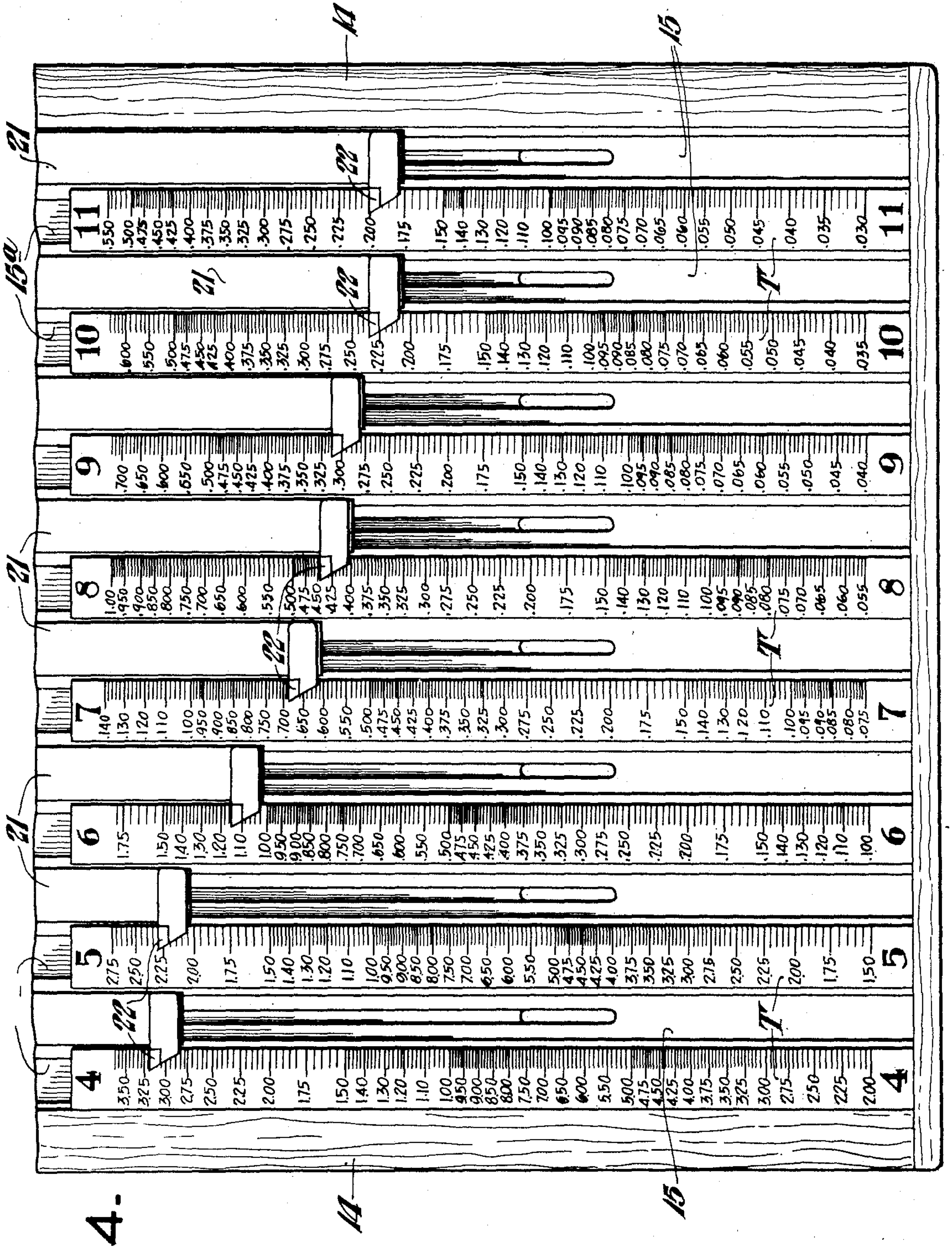

FIG. 4.

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SLIDE RULE

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FIG. 5.

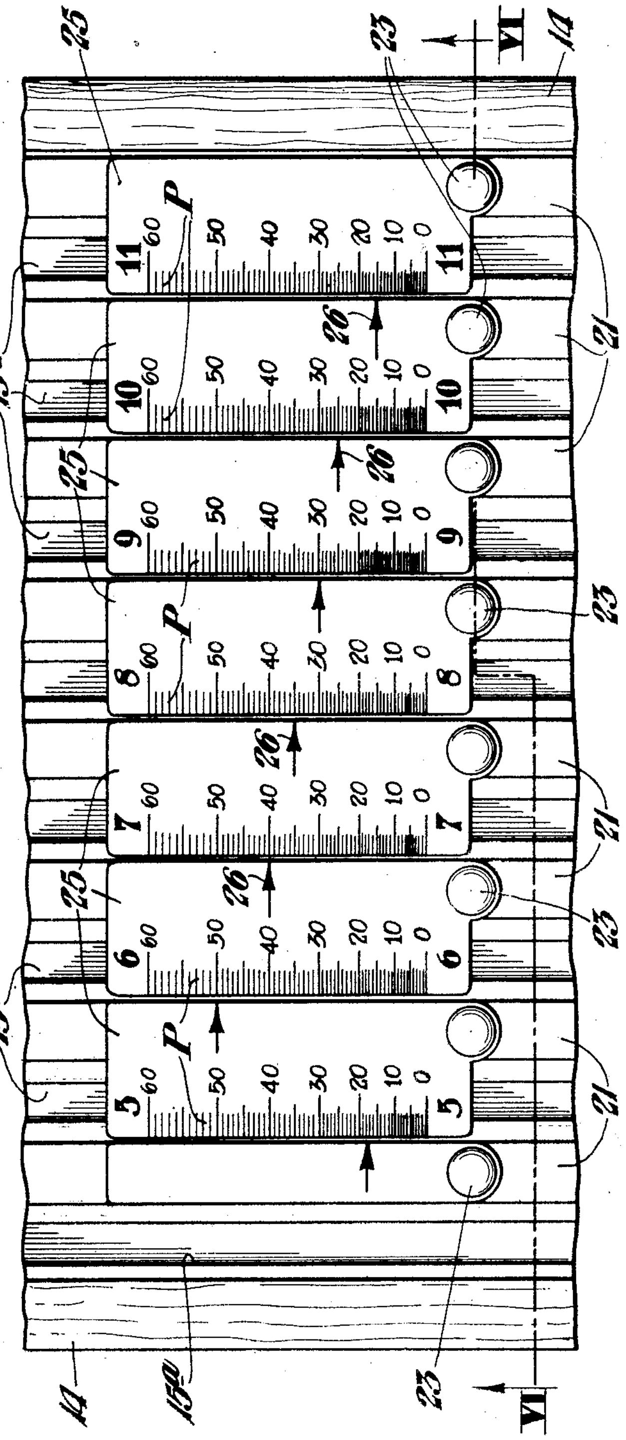
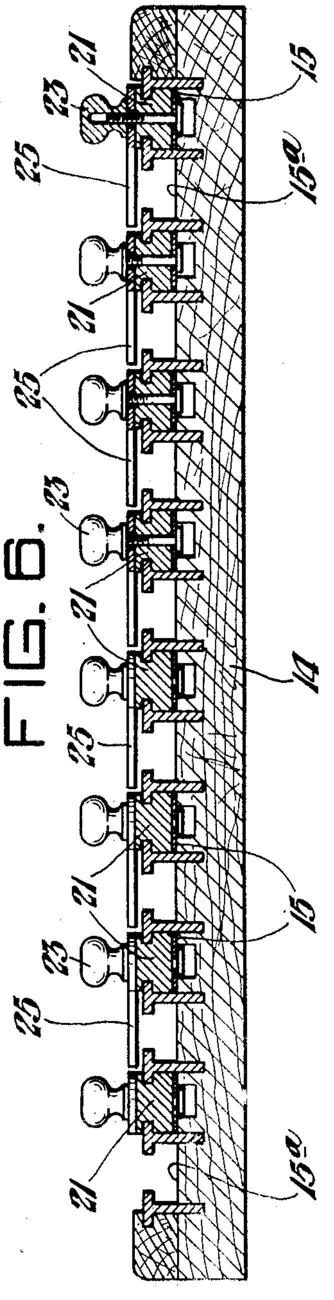


FIG. 6.



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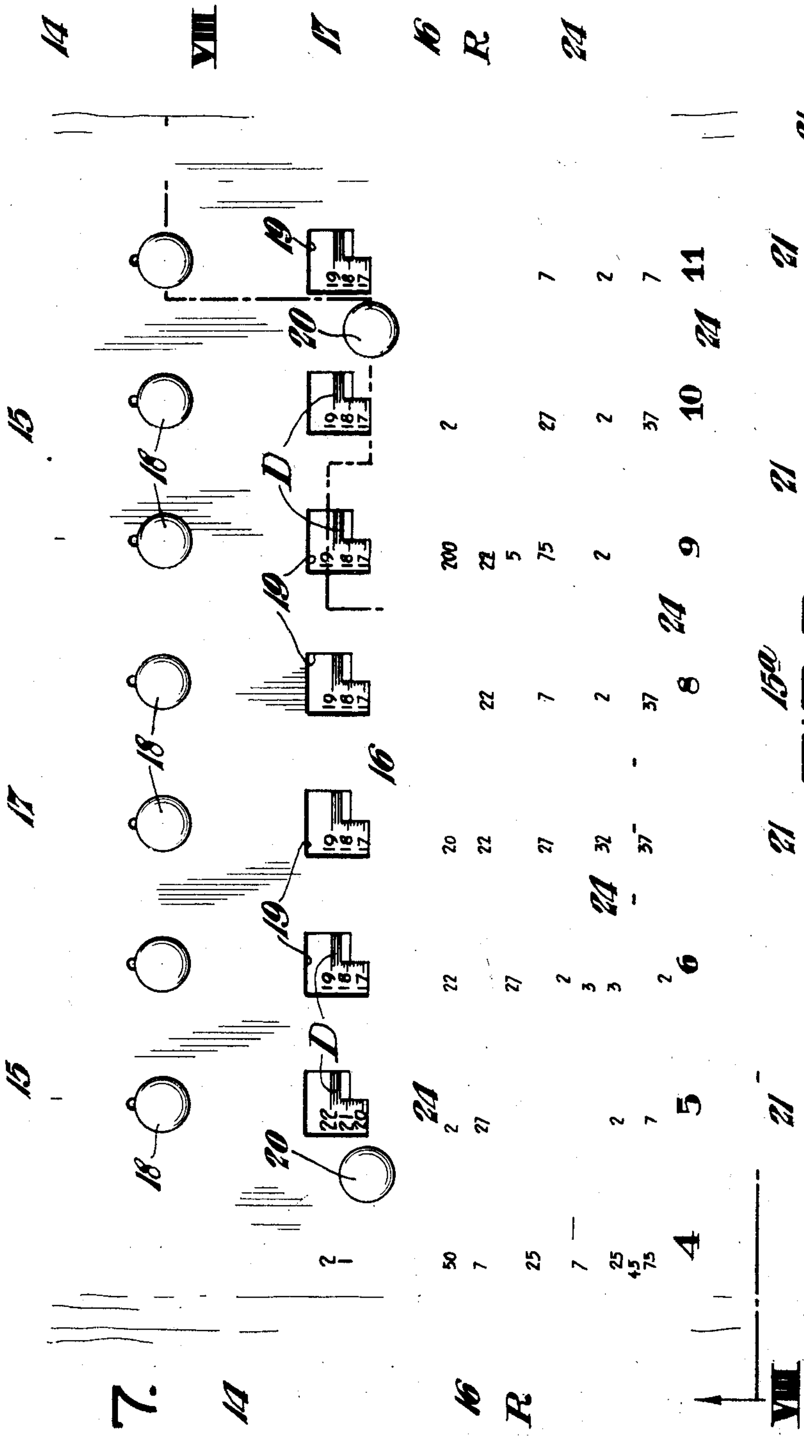

FIG. 7.

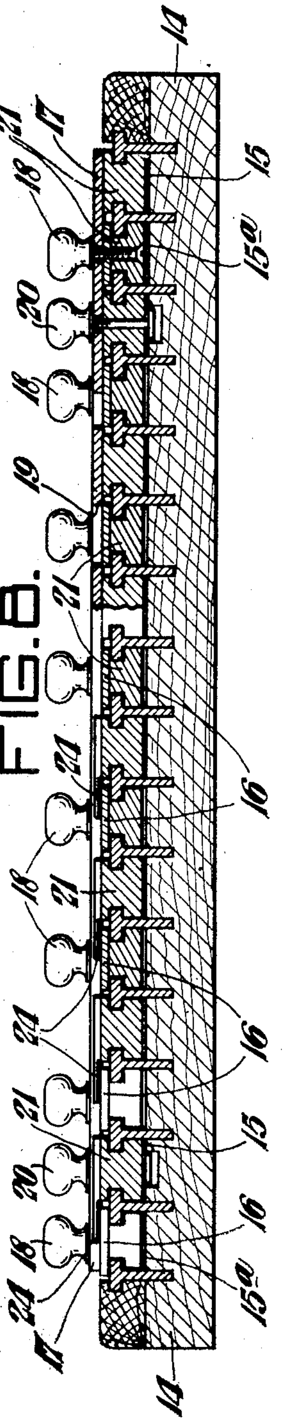

FIG. 8.

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SLIDE RULE

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FIG. 9.

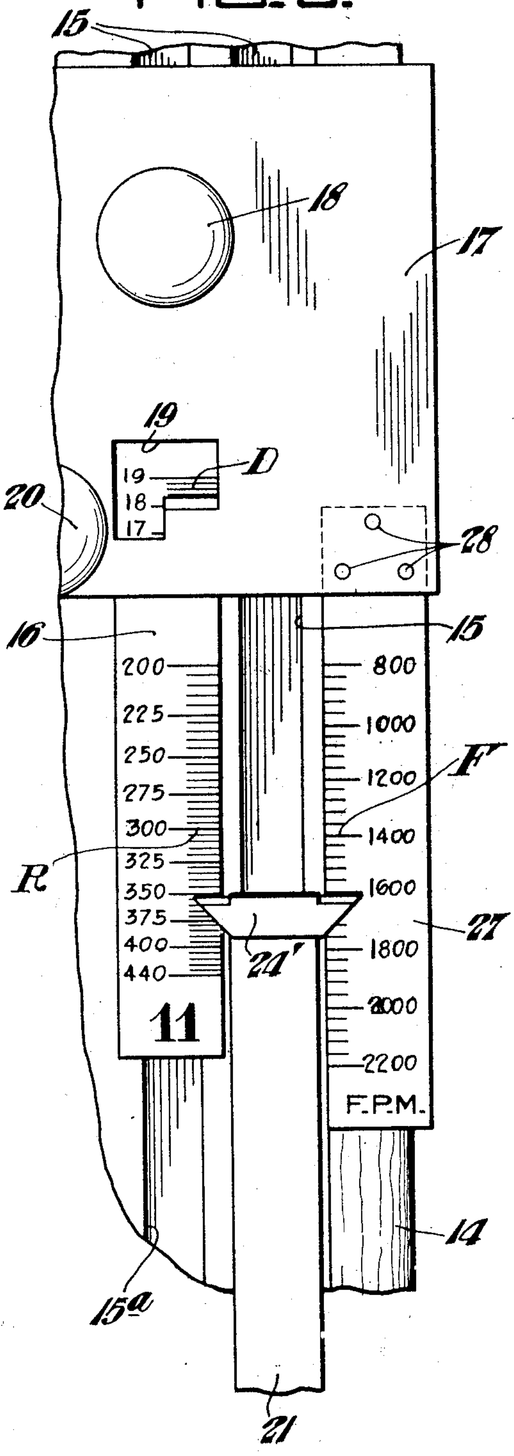
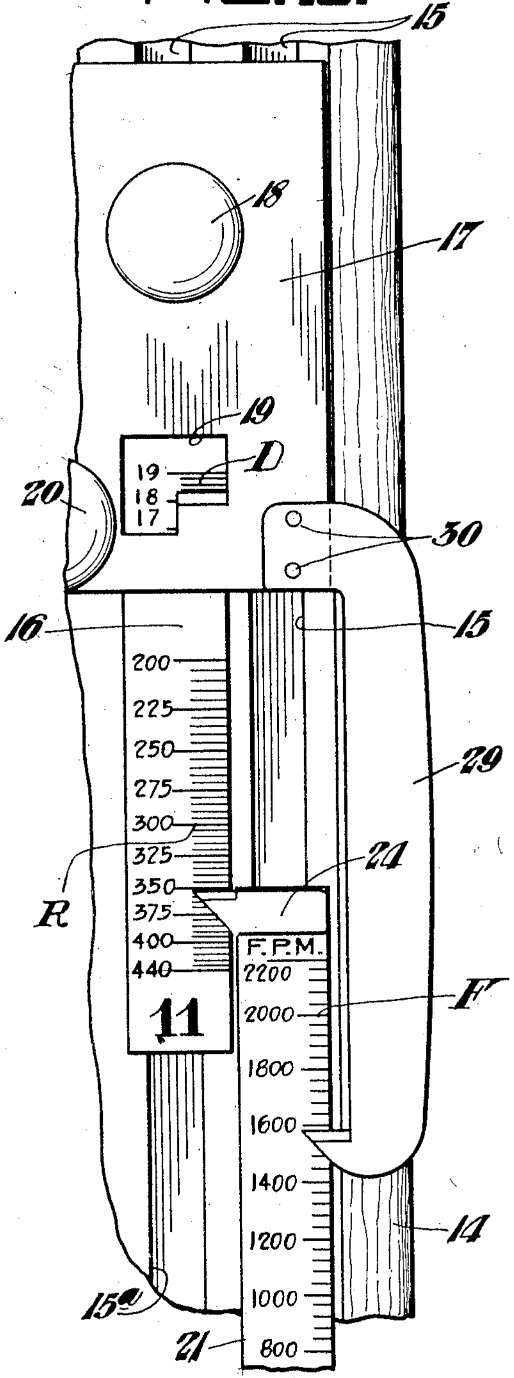


FIG. 10.



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UNITED STATES PATENT OFFICE

2,221,476

SLIDE RULE

Howard C. Goodrich, McDonald, Ohio

Application November 9, 1939, Serial No. 303,687

13 Claims. (Cl. 235—70)

This invention relates to a slide rule or device for calculating the value of variables in a series of interdependent mechanical operating units, and particularly to a multi-slide rule or device for determining the variable factors involved in setting up the individual roll stands of a mill train.

This application is a continuation-in-part of applicant's copending application, Serial No. 109,961, filed November 9, 1936.

One of the objects of this invention is to provide a multi-slide rule or device by which the value of each variable factor in a series of interdependent or correlated mechanical operating units can be directly determined and coordinated with all of the other operating factors which are involved in the series.

It is another object of the invention to provide a multi-slide rule or device for solving problems which involve more than one equation or set of relations between the variables entering into the general problem wherein some of the variables are known, and others, as many as there are equations in the case to be solved, are unknown.

It is a further object of the present invention to provide a simple and inexpensive multi-slide rule or device by which the mill operator can easily and conveniently determine the adjustment necessary on each roll stand of a mill train for providing a finished sheet of a predetermined thickness.

It is still another object of the invention to provide a multi-slide rule or device by which the mill operator can quickly and accurately determine the adjustment and setting necessary for each roll stand of a mill train when the desired thickness of the finished metal and the reduction capacities and speed ranges of the several mill stands are known.

Various other objects and advantages of this invention will be more apparent in the course of the following specification and will be particularly pointed out in the appended claims.

In the accompanying drawings there is shown, for the purpose of illustration, one embodiment which my invention may assume in practice.

In these drawings:

Figure 1 is a plan view of a continuous rolling mill system of the type with which the improved slide rule or calculator of my invention is adapted to be used;

Figure 2 is a longitudinal section through the roll stands thereof;

Figure 3 is a plan view of the improved slide rule or calculator of my invention;

Figure 4 is an enlarged fragmentary plan view of the lower portion of the slide rule as shown in Figure 3, showing the scales representing the roll opening;

Figure 5 is an enlarged fragmentary plan view of the middle portion of the rule showing the scales representing the percentage of reductions;

Figure 6 is a sectional view taken on line VI—VI of Figure 5;

Figure 7 is an enlarged fragmentary plan view of the upper portion of the slide rule showing the bridge and the scales representing the roll diameter and the speed of the motor;

Figure 8 is a sectional view taken on line VIII—VIII of Figure 7;

Figure 9 is a fragmentary plan view of the upper portion of the rule showing a slight modification; and,

Figure 10 is a similar view showing another modification.

The improved slide rule or calculator of my invention is shown and described as it is adapted for use in determining the adjustments necessary in each of the roll stands of a mill train in a continuous type rolling mill system, but it will be understood that this is merely for the purpose of illustration and that a slide rule or calculator similar in design may be adapted for use in determining the value of each variable factor present in any other similar series of interdependent or correlated mechanical operating units and the like.

In a continuous type rolling mill system, as is generally known, the product material is subjected to a reduction of thickness, and simultaneously to elongation in the several roll stands of the mill train, and the operation and performance in any one roll stand obviously bear a definite relation to the preceding and subsequent stands.

A general discussion of the problems involved in the operation of a continuous rolling mill system will first be stated in order to enable those skilled in the art to understand the nature and function of the slide rule or calculator of the present invention.

A fundamental condition of operation of this type of mill system is that equal volumes of product material must pass through each mill stand in equal periods of time. If this condition is not maintained, either of two difficulties will inevitably result: (1) If the volume of material passing through a given mill stand becomes less than the volume delivered by the preceding stand, an excess loop of material is developed between these two stands. This loop is likely to buckle, overlap, and be drawn between the rolls in doubled or twisted condition. This results in spoilage of the material, marring and often breaking of the rolls and the mill drive, resulting in shutdowns, expensive repairs, and loss of production. (2) If any mill stand tends to pull the material through in greater volume than can be supplied by the preceding mill stand, tension is developed in the material between these stands. This undue tension causes of the product material, resulting in non-uniformity in thickness and width, and consequently, a damaged product.

From the foregoing it will be apparent that, in accordance with the design and the operation of the continuous tandem mill system, accurate determination and rapid coordination of these operating factors, in each mill stand with respect to all other stands, which influence the volume of metal passing through the respective stands and the rate at which it passes through the stands; are essential.

The operating factors referred to above are those variables which are built into each stand of the mill train by the designer in order to provide the mill system with operating flexibility and with a range of product capacity. These operating factors are: mill drive motor speeds, work roll diameters, gear ratios between the mill drive motor and the respective work rolls, thickness of the material being worked and the percent reduction to which it may be subjected in each mill stand. The values of each of these factors, with the exception of the gear ratio, are designed to be variable, at the will of the operator, within limits dictated by proper mill design and operating considerations. The available variations in these operating factors are utilized to obtain, as desired, a diversified thickness of product, a range of production rates, a range of percentage reduction in each mill stand to obtain desired metallurgical results, a range of speed in each of the mill motor drives to provide for proper distribution of the load among the several mill drive motors and for maximum operating efficiency of the individual motors and of the entire mill system.

In order to obtain a maximum volume of production and to provide for equal volumes of product material being passed through successive mill stands at the same rate, it is necessary for the mill operator, as a preliminary to the rolling operation, to give complete and detailed consideration to the various ranges of each of these operating factors. His considerations are governed by the desired thickness of the finished product and the permanently fixed gear ratio which exists between each of the mill motor drives and their respectively driven work rolls. The original thickness of the material, the reduction to be made in the first and in each of the intermediate mill stands, the most satisfactory speed and load distribution among the mill drive motors, the successive percentages of reduction to be made in the first and following mill stands as influenced by the desired load distribution and by metallurgical qualifications are determined and set up before beginning rolling operations. Should it happen that the work rolls of some of the mill stands have been redressed or otherwise decreased in diameter, the operating result of this change must also be compensated for.

To enable the operator to comply with required condition of mill operation by developing the values of the variable operating factors which are involved in making a mill setup, the mill operator has recourse to two physical conditions upon which the necessary calculations may be based: (1) the variable operating characteristics of each particular mill and (2) the universally observed fact that in the reduction by rolling of metal in the shape of a wide slab, plate, or sheet, the plastic spread of the metal is of a negligible order and, consequently, for the purpose of calculating volume, the width of such a shape remains su the same throughout successive reductions.

Width in each stand $=W^1=W^2 \ldots =W^n$ (approximate)

The variable operating factors previously referred to, include the following:

(a) Work roll diameter for each stand $D=D^1, D^2 \ldots D^n$

Mill motor speed for each each stand $R=R^1, R^2 \ldots R^n$

Gear ratio between mill drive motor and work rolls $=G^1, G^2 \ldots G^n$

Percentage reduction in each stand $=P^1, P^2 \ldots P^n$

Thickness of material leaving each stand $=T=T^1, T^2 \ldots T^n$

The volume of metal, of any given width, operated upon in unit time in each of the roll stands varies within the ranges of roll speeds provided by the mill designer and also varies between the maximum and minimum adjustments of the respective roll openings. For a given setting of any stand all the other stands of the mill must be set to operate upon the same volume of metal in the same unit of time. That is to say, although each stand is designed to be adapted to a range of volume from V maximum to V minimum; for a particular volume of production V_p as set up for one stand, all other stands must be set up to operate upon a volume of metal equal to V_p.

$$V_p=V_p^1=V_p^2=V_p^3= \ldots =V_p^n \tag{1}$$

The numerical value V_p for a particular stand, and, similarly, for a particular mill system made up of a plurality of stands, is exclusively dependent upon the ranges of the previously stated variable operating factors, as identified above.

To determine this numerical value of V_p for a particular stand k, the following relationship between the variable operating factors and volume is developed:

$$V_p^k=T^k\times W^k\times L^k \tag{2}$$

L^k=length of material leaving the stand per unit of time
and,

$$L_k=\frac{\pi D^k\times R^k}{G^k} \tag{3}$$

Then, substituting this value in Equation 2:

$$V_k=\frac{T^k\times W^k\times \pi D^k\times R^k}{G^k} \tag{4}$$

Now, substituting in Equation 1:

$$\frac{T^1\times W^1\times \pi D^1\times R^1}{G^1}=\frac{T^2\times W^2\times \pi D^2\times R^2}{G^2}= \ldots \frac{T^n\times W^n\times \pi D^n\times R^n}{G^n} \tag{5}$$

In Equation 5 the "constants," such as π and W, are canceled out and the equation becomes:

$$\frac{T^1\times D^1\times R^1}{G^1}=\frac{T^2\times D^2\times R^2}{G^2}= \ldots \frac{T^n\times D^n\times R^n}{G^n}=K \text{ (mill constant)} \tag{6}$$

This is the tal equation for the mill,

and will be frequently hereinafter referred to.

In order to obtain the proper metallurgical characteristics in the product, and also to properly proportion the power requirements among the individual stands of the mill, the portion of the total reduction in thickness that is desired to be accomplished in each individual stand must be considered. This is referred to as "percent reduction".

$$(7)\qquad P^k = 100\text{ percent} - \frac{100T^k}{T^{(k-1)}}$$

This value is originally calculated, for each stand, by the mill designer, for the proposed range of products to be rolled on the mill. From an average P and maximum P for each stand, and other pertinent data, the designer calculates the average and maximum horsepower requirements for the stand and selects the proper size of motor. Once the mill is built, the value of P remains very close to an average figure. When this figure is known for each type of product, T for each stand can be easily calculated.

The values are now tabulated for a characteristic mill train. All of these figures are obtained from the mill designer. It will be noted that stands Nos. 1, 2 and 3 are not considered. This is due to the condition (a common one) that in this portion of the train the bar or slab is never in more than one set of rolls at a time; hence it is unnecessary to correlate these stands. In other words, Equation 1 hereinbefore referred to is true only when the bar is in two or more stands at the same time.

By the use of a formula obtained from Equation 7,

$$(8)\qquad T^{k-1} = \frac{100T^k}{100 - P^k}$$

the operator can start filling out his chart by calculating the successive values of T, from 11 stand on back, throughout the train:

$$T^{10} = \frac{100T^{11}}{100 - P^{11}}$$

$$T^{10} = \frac{100 \times .125}{100 - 15}$$

$$T^{10} = \frac{12.5}{85}$$

$$T^{10} = .147$$

In a like manner:

$$T^9 = .196$$
$$T^8 = .280$$
$$T^7 = .431$$
$$T^6 = .718$$
$$T^5 = 1.436$$
$$T^4 = 1.994$$

These values are duly recorded in the operator's chart (Table II).

The value of K is next calculated, using the figures for No. 11 stand in Equation 6. (This is the only stand for which the necessary figures are as yet available.)

$$K = \frac{T^{11} \times D^{11} \times R^{11}}{G^{11}}$$

$$K = \frac{.125 \times 21.340 \times 330}{1.608}$$

$$K = 547.43$$

Table I.—*Continuous mill—8 stands in continuous train*

	Stand No.							
	4	5	6	7	8	9	10	11
Gear ratio	20.250	14.539	7.370	4.706	3.330	2.590	1.890	1.608
Minimum motor R. P. M	250	250	220	200	200	200	200	200
Maximum motor R. P. M	500	500	440	400	400	400	400	400
Normal percent reduction		28	50	40	35	30	25	15
Maximum thickness	3.650	2.750	1.800	1.400	1.000	0.730	0.690	0.550
Minimum thickness	0.200	0.150	0.100	0.075	0.055	0.040	0.035	0.030
Maximum roll diameter	22.000	22.000	19.000	19.000	19.000	19.000	19.000	19.000
Minimum roll diameter	19.000	19.000	17.000	17.000	17.000	17.000	17.000	17.000

It is from this table, and from various metallurgical and production requirements, that the operator must calculate his "mill setup." It will be assumed that the customer's order calls for strip 0.125 inch thick, and, for convenience, assume that the metallurgical requirements are normal, allowing the operator to use the normal percent reductions for each stand. It will also be assumed that production requirements will be met by a mill delivery speed of 330 R. P. M. on the last stand. The values of D are obtained from the roll shop foreman, who usually paints them on the end of each roll. The operator now constructs a chart substantially as follows:

Table II

	Stand No.							
	4	5	6	7	8	9	10	11
P		28	50	40	35	30	25	15
T								.125
R								330
G	20.250	14.539	7.370	4.706	3.330	2.590	1.890	1.608
D	21.120	21.000	21.000	20.950	21.000	21.140	21.150	21.340
K								

By transposing Equation 6:

$$(9)\qquad R^k = \frac{KG^k}{T^kD^k}$$

The value of R for stand No. 10 is now calculated:

$$R^{10} = \frac{KG^{10}}{T^{10}D^{10}}$$

$$R^{10} = \frac{547.43 \times 1.890}{.147 \times 21.150}$$

$$R^{10} = 333$$

In a like manner by use of the above equation:

$$R^9 = 342$$
$$R^8 = 310$$
$$R^7 = 285$$
$$R^6 = 267$$
$$R^5 = 264$$
$$R^4 = 264$$

All of these values are entered on the operator's chart, which now appears as follows:

TABLE III

	Stand No.							
	4	5	6	7	8	9	10	11
P		28	50	40	35	30	25	15
T	1.904	1.436	0.718	0.431	0.280	0.196	0.147	0.125
R	264	264	267	285	310	342	333	380
G	20.250	14.539	7.370	4.706	3.330	2.590	1.890	1.608
D	21.120	21.000	21.000	20.960	21.000	21.140	21.150	21.340
K								547.42

The operator then checks to determine if the indicated revolutions per minute of each stand are within the available range of the respective stands. If not, a new speed for stand No. 11 must be assumed and all the speeds of the other stands recalculated.

The series of roll stands of the mill train hereinbefore referred to are shown diagrammatically in Figures 1 and 2 of the drawings. It will be seen as has been explained that in the preliminary stage of forming the strip, the bar or slab is not in roll stands Nos. 1, 2, 3 and 4 at the same time, that is, it leaves stand No. 1 before entering stand No. 2, and leaves stand No. 2 before entering stand No. 3 and leaves stand No. 3 before entering stand No. 4 and that the strip is in roll stands Nos. 4 to 11, inclusive, at one time, and hence it is necessary to correlate these last mentioned stands, as has been described. The rolls of each of the stands are driven by a gear reducer 12 which in turn is driven by a motor 13. It will be understood that the purpose of the slide rule of the present invention is to correlate the variable factors of each of the roll stands Nos. 4 to 11, inclusive, or the number of interdependent mechanical units or equations in the problem.

The slide rule or calculator of this invention is not designed to calculate values, but rather to indicate directly the relation of the value of each of the variable factors in any particular roll stand so that the variable factors in each of the other roll stands can be determined and indicated thereon which will satisfy all the relations severally embodied in the different roll stands and to properly coordinate them for any desired rolling problem. Such a slide rule must be designed for the particular mill train with which it is to be used, and it will be understood that this description is confined to a slide rule or calculator for use with the continuous mill hereinbefore discussed.

As shown in Figure 3 of the drawings, the improved slide rule of my invention comprises a rectangular shaped body member 14 having a plurality of slots or guide grooves 15 suitably arranged therein in side by side relation and parallel to each other and extending longitudinally thereof. These slots are preferably formed by embedding a plurality of longitudinally extending spaced apart T-shaped members in the base. At one end, preferably the lower end of the body member 14, there is securely arranged in any suitable manner in each of the alternate slots or grooves 15a, a thickness scale T in parallel relation to each others as is more clearly shown in Figure 3, which represents the distance between the rolls of the respective stands Nos. 4 through 11.

It will be understood that all the scales on the rule have a logarithmic ruling of any suitable base and it has been found that a base 10 logarithmic scale, measuring 10 inches to the cycle, is most convenient as it is easily read to the required degree of accuracy and at the same time permits a sufficiently compact rule. Once the length per cycle is established, the same ruling must be continued on all scales of the device. For this discussion a log base 10 of 10 inches per cycle will be employed.

The maximum and minimum values indicated on each of these scales are the maximum and minimum values of thickness that can be rolled on that particular stand which the scale represents, as indicated by Table I (obtained from the mill designer).

Thus, for No. 11 stand, that portion of the logarithmic scale from .030 in one cycle to .550 in the next cycle higher, or a section of ruling 12.63 inches long would be used. The length of this scale and all the other scales may be readily determined by the following formula:

(10)

$$\text{Length of scale} = \text{Length of cycle} \times \log\left(\frac{\text{max.}}{\text{min.}}\right)$$

then,

$$\text{Length of No. 11 thickness scale} = 10 \times \log\left(\frac{.550}{.030}\right)$$

$$= 10 \times 1.2633$$

$$= 12.633 \text{ inches}$$

The location of the decimal point is not considered on the ordinary slide rule. On this device, however, the rulings are indexed to indicate direct reading. No. 11 thickness scale, for example, is marked from .030 inch to .550 inch at suitable intervals along the scale.

As is more clearly shown in Figures 7 and 8, there is slidably arranged in each of the slots 15a adjacent the top end of the body member 14 opposite the roll spacing scales T, a movable slide member 16 having a pair of logarithmic scales arranged thereon with one of the scales D representing the diameter of the rolls and the other scale R therein representing the speed of the motor of the respective stands. There is movably arranged above and transversely of the slide members 16 and the body member 14, a movable plate-like bridge or slidable member 17 to which the upper ends of each of the slide members 16 are releasably attached by means of a clamping thumb screw 18. There is arranged in the bridge member 17 a plurality of window openings 19, with one positioned opposite each of the slide members 16. Each of the windows 19 has a knife edge or other suitable pointer or indicating means associated therewith which is securely fixed to the bridge member. The entire bridge plate assembly is arranged to slide longitudinally of the body member 14 and adapted to be locked thereto by means of a pair of clamping thumb screws 20 cooperating with the body member, and the slide members 16 are slidably arranged relative to both the body member and the bridge member.

The logarithmic scale R indicating the maximum to the minimum speeds of the motor of each roll stand is marked along the lower portion of each of the respective slide members 16 and the scale is inverted with respect to the thickness scales T for reasons hereinafter to be explained. This scale is also indexed so that it indicates a direct reading and the slide member corresponding to No. 11 stand is indexed from 200 to 400, representing revolutions per minute of the motor of that stand and the other scales are similarly indexed to correspond to the speeds of the respective motors of each of the roll stands.

By the use of formula No. 10, it will be found that the length of the scales representing the speed of the motor should be 3.010 inches for each stand of this particular mill and that the length of the scales representing the diameter of the rolls for the last six stands, namely stands Nos. **6** through **11**, should be 0.483 inch and for the first two stands, namely, stands Nos. **4** and **5**, should be 0.637 inch. The scales representing the diameter of the rolls are disposed opposite each of their respective windows **19** in the bridge member and are inverted relative to the scales representing the speeds of the motor and extend from the minimum to the maximum roll sizes as shown in Table I. The knife edge of each of the windows **19** cooperates with the roll diameter of the respective slides to indicate the reading thereon. There is preferably a blank space between each of these two scales so that the portion of the bridge plate between each of the windows and the speed scales will not mask or cover the scale markings on the respective slide members **16**.

There is slidably arranged in each of the slots or grooves **15**, preferably by means of a longitudinal groove arrangement between each of the thickness scales T and the slide members **16** disposed in the alternate slots **15**^{a}, a longitudinally extending slide member **21** having a pointer **22** or other suitable indicating means securely arranged therewith adjacent the bottom end thereof which cooperates with the thickness scale T. The minimum length of each of the slides **21** is the sum of the lengths of the thickness scale T and the speed scale R representing the respective roll stands.

Each of the slides **21** is adapted to be releasably clamped to the body member **14** by means of a clamping thumb screw **23** arranged intermediate the length thereof. On the upper or opposite end of each of the slides **21** there is securely fixed thereto a similar pointer **24** or other suitable indicating means which cooperates with speed scale R on each of the respective slide members **16**. However, in constructing and assembling the rule the pointer **24** on the top end of the slide **21** representing the last roll stand or stand No. **11**, is first securely fixed to that slide. A typical "setup" for the mill train, as shown in Table III is then made, and from this chart all the slides **21** are positioned so that the lower pointers **22** indicate the correct reading on each of the respective thickness scales T. Each of the slides **16** is then positioned so as to indicate through the windows **19** the correct sizes of the rolls on the roll diameter scales D of the respective roll stands and each of the slides **16** is clamped to the bridge member **17** by means of the clamping screws **18**. The bridge member together with the slide members **16** rigidly clamped thereto is then moved downwardly on the body member until the pointer **24** on the upper end of the slide **21** representing roll stand No. **11** indicates the correct speed on speed scale R of the respective slide **16**. The bridge member together with the slides **16** carried thereby is then locked in position by means of the pair of clamping screws **20**. Each of the other upper pointers **24** is then securely fixed to its respective slide **21** so that it indicates the correct reading on the respective speed scales R on the slide **16** of the respective roll stands as shown by the Table No. III. Thus, it will be seen that each of the slides **16** and each of the respective slides **21** constitutes a plurality of sets of slides in which any one respective pair or set represents one roll stand.

The percentage of reduction indicia members **25** are now assembled on the rule. It is convenient to make these members equal in width to the combined width of the slide **21** and thickness scale T, less sufficient clearance. The percentage of reduction scale P on the indicia members **25** is also logarithmic, having the same base and cycle as the other scales, and is inverted with respect to the thickness scales T. The portion of the logarithmic scale from .4 to 1. is chosen as being the most convenient, since it covers a range from zero percent to sixty percent reduction, but any range equal to, or greater than, the percent reduction range of the particular stand to which it applies will be suitable. These scales are indexed with a zero percent at the 1.0 ruling, a ten percent at the .9 ruling, a twenty percent at the .8 ruling, etc. The reason for this is apparent from a study of Formula 7. These are securely fixed in any suitable manner to the slides **21** preferably in a straight line across the rule, so that a quick glance at the rule will indicate any variation from characteristic percent reductions on any mill "setup." The index pointers, preferably arrow-heads **26** are located in such a position as to give the readings indicated on the "setup" Table No. III. It will be understood that all of the scales numbered **4** through **11** represent the roll stands Nos. **4** through **11**, respectively. This completes the construction and calibration of the rule and its use will now be explained.

Attention is directed to the fundamental mill formula:

$$(6)\quad \frac{T^1\times D^1\times R^1}{G^1}=\frac{T^2\times D^2\times R^2}{G^2}=\ldots=\frac{T^n\times D^n\times R^n}{G^n}$$

and the effect of varying the values of one or more of the factors in any one member of the equation, or of all members at the same time will readily be observed and it will be seen that the slide rule of the present invention performs this function easily and accurately.

The variation of the factor T in one set of relations of the equation only will first be considered. It will be obvious that a constant value for the entire set must be maintained by correspondingly increasing the value of some other factor if the value of T is decreased and vice versa. If the slide rule is operated to increase or decrease the value of T for any one stand, it is done by moving only the slide **21**, leaving the bridge assembly clamped at **20** and the slide **16** clamped at **18**. When the slide is released at **23** and moved up and down so that pointer **22** indicates varying thickness, it will be noted that pointer **24** also solidly fixed to slide **21** moves up and down therewith indicating varying speeds on scale R. Since both R and T are logarithmic scales on the same base and with the same length of cycle, it will be seen that the product of the values of R and T will be a constant for any particular "setup." This fact maintains the Equation 6 by keeping a constant value for the member in which the factors are varied. The thickness scale T is now varied at will, knowing that any changes will be compensated for by a corresponding corrective change in the value of R.

In a like manner, if all other slides and scales remain clamped and only one clamp 18 loosened, any particular slide 16, the roll diameter indication can be varied at the knife edge of window 19 by moving the respective slide 16. This also moves the speed scale R of slide 16 under pointer 24 in such a manner as to keep the value of the product of D and R constant. Thus, it will be seen that if it is desired to vary the speed of any one roll stand, a corresponding change in T must be made by moving slide 21. Another way in which to vary speed on the device is to loosen clamping screws 20 (keeping all other clamping screws tight) and moving the entire bridge assembly until the desired value is reached for any particular stand. This has the mathematical effect of making a proportionate change in each member of Equation 6 so that the value of the members, although changed numerically, remains equal to each other.

It will be understood that there are three types of adjustment that can be made on the slide rule or calculator of the present invention: namely, adjustment for roll size, adjustment for roll opening, percent reduction and motor speeds, and adjustment for finishing speed. The adjustment for roll size in any particular stand is made by turning the clamping screw 18 so as to release the slide 16 representing the particular stand for which the roll slide adjustment is to be made. The slide is then moved until the correct roll size appears opposite the index in the window 19. The clamping screw 18 is then turned so as to reclamp and lock the slide 16 in position. This adjustment need be made only when rolls are changed in the mill and it need not be touched when changing to a different finished thickness of strip.

The adjustment for roll opening, percent reduction, or motor speed on any particular stand is made by turning the clamping screw 23 so as to release the slide 21 representing the roll stand on which the adjustment is to be made and the slide 21 is moved and the adjustment made relative to the roll opening, on scale T, percent reduction on scale P, or motor speed on scale R, whichever is desired and the slide is then reclamped and locked in position by means of the clamping screw 23. This will be further discussed hereinafter.

The adjustment for the finishing speed is made by moving the bridge assembly which carries with it the motor speed scales R. The bridge 17 is moved by grasping the clamping thumb screws 20 and moving the bridge so that the scales R are positioned as desired opposite the pointers 24 and the clamping screws 20 are then turned so as to lock the bridge together with the slides 16 carried thereby in position.

It will be seen that the slide rule of the present invention has a number of useful functions, the most important being to predetermine the correct roll opening and motor speeds for any particular thickness of finished sheet material desired within the range of the mill train. To determine the correct roll opening and motor speeds of each of the roll stands by means of this device, the correct roll sizes are first set up on scales D of the slides 16, as has been described. The slide 21 representing the last finishing stand is then positioned and clamped so that the pointer 22 carried thereby indicates the desired thickness of the finished material on thickness scale T. The next to the last slide 21 representing the roll stand No. 10 on the stand preceding the last stand is then positioned so that the arrow 26 on the indicia member 25 carried thereby indicates on scale P on the indicia member 25 carried by the slide 21 representing the last stand the percent reduction desired on stand No. 11 or the last stand. The percent reduction for each stand is characteristic for each individual rolling mill and does not vary greatly for each strip to be reduced and it is calculated or more or less from experience. As has been explained, the slide rule is so constructed that when these characteristic percentages of reduction are set up for each stand, the scales P will be positioned in substantially a straight line across the rule. It is realized, however, that conditions often arise when the variations of even ten or twenty percent from the characteristic reductions must be used. These variations must be determined by the speed operator, roller, foreman, or the person designing the slide rule.

All the other slides 21 are then su positioned relative to the scales P as and clamped in position. The bridge 17, with the slide members 16 carried thereby, is then moved so that the desired finishing speed is indicated on the speed scale R by the pointer 24 carried by the slide 21. All the indicated roll openings for the respective roll stands are then recorded and sent to the roller and all the motor speeds are noted and given to the speed operator.

To determine the actual roll opening at each stand in order to recalibrate the roll opening indicators on the stands, the finishing stand slide 21 is positioned at the actual finished on scale T of the strip as measured by the gager. The speed of the motor of the last finishing stand is then ascertained by means of a tachometer and the bridge is moved so that the actual motor speed as found is indicated on the scale R of the slide 16 for that stand. The other slides 21 are then positioned so as to indicate the actual motor speeds as found by the aid of the tachometer on the other stands, and the correct roll openings are then noted from each of the scales T.

To determine the actual percentage of reduction occurring in each stand, the slides are manipulated as above and the percentage of reduction noted on the scales P.

To balance up a mill when some motors are under excessive loads, the slide rule is set to actual rolling conditions at the time. The slides 21 are then adjusted to permit lighter on those stands in which the motor is ov and the new roll openings and motor speeds are noted and the necessary corrections made to each stand.

To determine whether or not a finished sheet of any particular thickness can be rolled on the mill from a given size slab, the slide rule is set up as the sheet would be rolled. The motor speed scales R are then noted to see if the motor speeds fall within the available ranges and the percent reduction scales P are noted to see if tic reductions will be made on each of the stands.

In Figures 9 and 10 of the drawings, there are shown two forms of an additional scale which may be incorporated with the slide rule or calculator of the present invention if desired. The scale as shown in Figure 9 comprises an indicia member 27 carried by the bridge member 17 which is securely attached thereto in any suitable manner as at 28 and extends downwardly preferably from the right hand edge thereof next to the slide 21 representing roll stand No. 11 or the last stand in the mill train parallel to the slides 16. However, this indicia member may be attached to the bridge in any other convenient position so long as it is parallel to the movement thereof. There is arranged on the indicia member 27, markings or a delivery speed scale F representing the speed of the strip in feet per minute as it is delivered from the last stand and the mill train. The upper pointer 24′ arranged on the upper end of the slide 21 representing stand No. 11 is constructed so that it cooperates with both the speed scale R on slide 16 and the delivery scale F on the indicia member 27. The delivery scale or markings F are arranged similar to the speed scale R, that is, inverted relative to the thickness scale T. The delivery scale F is also a logarithmic scale having the same base and same length per cycle as the other scales of the rule.

In Figure 10 there is shown another way in which the scale representing the speed of the strip as it is delivered from the mill can be designed. In this construction the delivery or marking scales F representing feet per minute are arranged on the upper end of the slide 21 representing roll stand No. 11 or the last stand just below the upper pointer 24 carried thereby and is inverted relative to the speed scales R. A pointer 29 which is adapted to cooperate with the scale F is securely attached to the right hand edge of bridge member 17 as at 30 and extends downwardly along the slide 21. The pointer 29 is located relative to the scale by calculating the mill delivery speed for the same "setup" as is used in originally calibrating the rule by the following equation:

$$(11)\quad \text{Delivery speed}=\frac{\pi\times\text{Roll diameter in feet}\times\text{Motor R. P. M.}}{\text{Gear ratio}}$$

and the pointer is arbitrarily mounted to indicate this value, at the same time making certain that all the values are set up according to Table III. It will be understood that the proper position of a logarithmic ruling for the delivery scales F is selected which covers the available range of the delivery speed of the mill. This range is obtained from the mill designer.

As a result of this invention it will be seen that there is provided a slide rule or calculator by which the mill operator can easily and quickly determine the speed of the motor, the roll opening, and percent reduction of each of the roll stands and the speed of the strip as it is delivered from the mill for any desired thickness of finished strip without any calculation or the aid of any other devices.

While I have in this application specifically described one embodiment and several modifications thereof which my invention may assume in practice, it will be understood that these embodiments are merely for the purpose of illustration and description and that various other forms may be devised within the scope of my invention, as defined by the appended claims.

I claim:

1. A slide rule for the solution of a problem involving a number of unknown variables comprising a body member, a plurality of sets of slides arranged in parallel relation to each other on said body member, a bridge member arranged adjacent one end of said body member, said bridge member being arranged transversely of said body member and said sets of slides and being movable longitudinally thereof, each of said sets of slides consisting of a pair of slides with one arranged longitudinally of the body member and the other being adjustably attached to said bridge member and extending alongside and between the other of said slides parallel thereto, scales carried by each of said slides representing the variables entering into the general problem of the rule with all scales pertaining to each set of slides constituting together an embodiment of one set of relations between the variables of the rule problem, and coacting to indicate on the various scales the values representing the unknown variables in that set in their proper relation to each other, each set of slides having at least one of the scales associated therewith cooperating with the next succeeding set of slides so that the slides can be successively positioned in the several sets in order that the scales thereon will coact to indicate the values of the unknown variables which will satisfy all the relations severally embodied in the different sets of slides of the rule.

2. A slide rule for the solution of a problem involving a number of unknown variables comprising a body member, a plurality of slides arranged in parallel relation in said body member, a scale carried by said body member between each of said slides adjacent one end thereof, an indicator arranged on and adjacent the end of each of said slides cooperating with the scale located between that slide and the next succeeding slide, an indicia member securely arranged on each of said slides intermediate the length thereof parallel to each other, each of said indicia members having a scale arranged along one edge thereof and an indicating means carried on the opposite edge thereof which is adapted to cooperate with the scale on the next succeeding indicia member, a movable bridge member arranged transversely of said body member and said slides adjacent the opposite end thereof beyond the indicia members, a plurality of spaced apart slide members carried by said bridge member, said slide members being equal in number to the number of said first mentioned slides and being positioned therealongside parallel thereto so as to provide a plurality of sets of slides, each of said last mentioned slide members having a scale arranged thereon and being movable relative to both said bridge member and said body member, an indicator arranged on each of said first mentioned slides opposite each of the scales of said second mentioned slides with which they are adapted to cooperate, said scales carried by the body member and each of the slides representing variables entering into the general problem of the rule and all the scales pertaining to any one set of slides constituting together an embodiment of one set of relations between the variables of the rule problem, and coacting to indicate on the various scales the values representing the unknown variables in that set in their proper relation to each other with any one set of said slides adapted to be adjusted according to the known variables so as to indicate the unknown variables in that set and the other of said sets of slides adapted to be successively located relative thereto and coacting to indicate the values of the unknown variables which will satisfy all the relations severally embodied in the different sets of slides of the rule.

3. In a device for determining the adjustment necessary in a mill train for producing a finished sheet of a predetermined thickness, the combina-

tion of a body member, a plurality of sets of slides arranged in parallel relation to each other in said body member and being equal in number to the number of roll stands in the mill train, a bridge member arranged adjacent one end of said body member, said bridge member being arranged transversely of said body member and said sets of slides and being movable longitudinally thereof, each of said sets of slides consisting of a pair of slides with one arranged longitudinally of the body member and the other being adjustably attached to said bridge member and extending alongside the other of said slides parallel thereto, scales carried by said body member and said sets of slides representing the variables including the roll opening, percentage of reduction, motor speed, and diameter of the rolls with all the scales pertaining to each set of slides constituting together the above named variable factors in one roll stand and coacting to indicate on the various scales the values representing the unknown variables in that stand in their proper relation to each other, each set of slides having at least one of the scales associated therewith cooperating with the next succeeding set of slides so that the slides can be successively positioned in the several sets in order that the scales thereon will coact to indicate the values of the above mentioned unknown variables on the scales of the other of said sets of slides which will satisfy all the relations severally embodied in the different sets of slides and each roll stand.

4. In a device for determining the adjustments necessary in a mill train for producing a finished sheet of a predetermined thickness, the combination of a body member, a plurality of sets of slides arranged in parallel relation to each other on said body member and being equal in number to the number of roll stands in the mill train, a bridge arranged adjacent one end of said body member, said bridge member being arranged transversely of said body member and said sets of slides and being movable longitudinally thereof, each of said sets of slides consisting of a pair of slides with one arranged longitudinally of the body member and the other being adjustably attached to said bridge member and extending alongside and between the other of said slides parallel thereto, each of said slides having thereon at least a logarithmic scale representing the diameter of the rolls and another scale representing the speed of the motor with each scale representing the diameter of the rolls coacting with the corresponding one of a plurality of indicators associated with said bridge and each scale representing the speed of the motor coacting with a pointer carried by each of the longitudinally extending slides, cooperable means arranged between said body member and each of the longitudinally extending slides for indicating the roll opening, each of said longitudinally extending slides having a logarithmic scale securely arranged thereon representing the percentage of reduction, with said scales being substantially in parallel alignment with each other, each of said last mentioned scales except the last one thereof having a pointer for coacting with the graduations on the next succeeding scale.

5. In a device for determining the adjustments necessary in a mill train for producing a finished sheet of a predetermined thickness, the combination of a body member, a plurality of sets of slides arranged in parallel relation to each other in said body member and being equal in number to the number of roll stands in the mill train, a bridge member arranged adjacent one end of said body member, said bridge member being arranged transversely of said body member and said sets of slides and being movable longitudinally thereof, each of said sets of slides consisting of a pair of slides with one arranged longitudinally of the body member and the other being adjustably attached to said bridge member and e alongside the other of said slides parallel thereto, scales carried by said body member and said sets of slides representing the variables including the roll opening, percentage of reduction, motor speed, and diameter of the rolls with all the scales pertaining to each set of slides constituting together the above named variable factors in one roll stand and coacting to indicate on the various scales the values representing the unknown variables in that stand in their proper relation to each other, each set of slides having at least one of the scales associated therewith cooperating with the next succeeding set of slides so that the slides can be successively positioned in the several sets in order that the scales thereon will coact to indicate the values of the above mentioned unknown variables on the scales of the other of said sets of slides which will satisfy all the relations severally embodied in the different sets of slides and each roll stand, and means carried by said bridge member cooperating with one of said longitudinally extending slides for indicating the rate of speed the sheet is being delivered from the mill train.

6. In a device for determining the adj necessary for each unit of a series of interdependent mechanical operating units, the combination of a body member, a plurality of sets of slides arranged in parallel relation to each other and being equal in number to the number of mechanical units, a bridge arranged adjacent one end of said body member, said bridge being arranged transversely of said body member and said sets of slides and being movable longitudinally thereof, each of said sets of slides consisting of a pair of slides with one arranged longitudinally of the body member and the other being adjustably attached to said bridge and extending along side of the other of said slides parallel thereto, scales carried by said body member and said sets of slides representing the variables of each of the units with all the scales pertaining to each set of slides constituting together an embodiment of the variable factors in one unit and coacting to indicate on the various scales the values representing the unknown variables in that unit in their proper relation to each other and with any one set of slides adapted to be adjusted according to the known variables so as to indicate the unknown variables in the unit pertaining to that set of slides, and the other of said sets of slides adapted to be successively located relative thereto and coacting to indicate the values of the unknown variables on the other set of slides which will satisfy all the relations severally included in the different sets of slides and each unit.

7. An apparatus for determining the adjustment necessary for each roll stand in a mill train for producing a finished sheet of predetermined thickness comprising a body member, a plurality of slides equal in number to the number of roll stands in the mill train secured to said body member at its lower end, logarithmic graduations on said body member between said slides for indicating the minimum and maximum rolling requirements for each roll stand in said mill

train, the last logarithmic graduation representing the last roll stand, pointers carried by said slides, the pointer on the last slide cooperating with the logarithmic graduations representing the last roll stand to indicate the metal thickness of the finished product, logarithmic graduations carried by said slides and positioned above said first mentioned logarithmic graduations, pointers fixed to said slides for cooperation with said last mentioned logarithmic graduations to indicate the percentage reduction of the metal of the respective roll stands in the mill train and a bridge adjustably attached to the body member transversely of said slides, slides carried by said bridge and extending between said first mentioned slides, upper and lower logarithmic graduations on said slides carried by said bridge, the upper graduations cooperating with a pointer carried by said bridge to determine the diameter of the rolls for each roll stand, the lower graduations cooperating with pointers carried by the first mentioned slides to indicate the speed of the motor for each roll stand.

8. In a calculator, the combination of a body, a plurality of sets of slides and a bridge, the bridge being adjustably attached to the body transversely of the said sets of slides, each set of slides comprising a first slide and a second slide, the first slide being adjustably secured to the said bridge and having an upper set and a lower set of logarithmic graduations, each upper set coacting with a corresponding one of a plurality of pointers fixed to the said bridge and each lower set of graduations coacting with an upper one of a set of two pointers fixed to each of the said second slides, each of the lower one of said two pointers coacting with a corresponding one of a series of parallel logarithmic scales stationarily attached to said body, each of said second set of slides having a logarithmic scale fixedly secured thereon and forming a series, each of the last named scales except the last one thereof having a pointer for coacting with the graduations of the next following of the said series.

9. A slide rule for the solution of a problem involving a number of unknown variables comprising a body member, a plurality of sets of slides arranged in parallel relation to each other on said body member, means arranged transversely of said body member and said sets of slides and which is movable longitudinally thereof, each of said sets of slides consisting of at least a pair of slides with one slide of each set attached to said movable transverse means and extending alongside and between the other of said slides parallel thereto which is carried by said body member, scales and indicators arranged on said slides with said scales representing the variables entering into the general problem of the rule with all scales pertaining to each set of slides constituting together an embodiment of one set of relations between the variables of the rule problem, and coacting to indicate on the various scales the values of the unknown variables in that set in their proper relation to each other, the other slide of each set of slides carried by the body member having a scale arranged thereon cooperating with an indicator on the corresponding slide of the next succeeding set of slides so that the slides can be successively positioned in the several sets in order that the scales of each set will coact to indicate the values of the unknown variables which will satisfy all the relations severally embodied in the different sets of slides of the rule.

10. In a device for determining the adjustments necessary for each unit of a series of interdependent mechanical operating units, the combination of a body member, a plurality of sets of slides arranged on said body member in parallel relation to each other and being equal in number to the number of mechanical units, a slidable member arranged transversely of said body member and said sets of slides and which is movable longitudinally thereof, each of said sets of slides consisting of at least a pair of slides with one slide of each set attached to said slidable member and extending alongside and between the other of said slides which is carried by said body member, scales and indicators arranged on said slides with said scales representing the variables of each of the units with all the scales pertaining to each set of slides constituting together an embodiment of the variable factors in one unit and coacting to indicate on the various scales the values of the unknown variables in that unit in their proper relation to each other and with any one set of slides adapted to be adjusted according to the known variables so as to indicate the unknown variables in the unit pertaining to that set of slides, and the other of said sets of slides adapted to be successively located relative thereto and coacting to indicate the values of the unknown variables on the other set of slides which will satisfy all the relations severally included in the different sets of slides and each unit.

11. In a device for determining the adjustments necessary for each unit of a series of interdependent mechanical operating units, the combination of a body member, a plurality of sets of slides arranged on said body member in parallel relation to each other and being equal in number to the number of mechanical units, a slidable member arranged transversely of said body member and said sets of slides and which is movable longitudinally thereof, each of said sets of slides consisting of at least a pair of slides with one slide of each set attached to said slidable member and extending alongside and between the other of said slides which is carried by said body member, scales and indicators arranged on said slides with said scales representing the variables of each of the units with all the scales pertaining to each set of slides constituting together an embodiment of the variable factors in one unit and coacting to indicate on the various scales the values of the unknown variables in that unit in their proper relation to each other, the other slide of each set of slides carried by the body member having a scale arranged thereon cooperating with an indicator on the corresponding slide of the next succeeding set of slides in that the slides can be successively positioned in the several sets in order that the scales of each set will coact to indicate the values of the unknown variables which will satisfy all of the relations severally embodied in the different sets of slides and each unit.

12. In a device for determining the adjustments necessary for each roll stand in a mill train for producing a finished sheet of a predetermined thickness, the combination of a body member, a plurality of sets of slides arranged on said body member in parallel relation to each other and being equal in number to the number of roll stands in the mill train, means arranged

transversely of said body member and said sets of slides and which is movable longitudinally thereof, each of said sets of slides consisting of at least a pair of slides with one slide of each set attached to said movable transverse means and extending alongside and between the other of said slides parallel thereto which is carried by said body member, scales and indicators arranged on said slides with the scales representing the variables including the roll opening, percentage of reductions, motor speed, and diameter of the rolls with all the scales pertaining to each set of slides constituting together the above named variable factors in one roll stand and coacting to indicate on the various scales the values of the unknown of the above variables in that stand in their proper relation to each other, the other slide of each set of slides carried by the body member having a scale arranged thereon cooperating with an indicator on the corresponding slide of the next succeeding set of slides so that the slides can be successively positioned in the several sets in order that the scales of each set will coact to indicate the values of the above mentioned unknown variables on the scale of the other of said sets of slides which will satisfy all the relations severally embodied in the different sets of slides and of each roll stand.

13. In a device for determining the adjustments necessary for each roll stand in a mill train for producing a finished sheet of a predetermined thickness, the combination of a body member, a plurality of sets of slides arranged on said body member in parallel relation to each other and being equal in number to the number of roll stands in the mill train, means transversely of said body member and said sets of slides and which is movable longitudinally thereof, each of said sets of slides consisting of at least a pair of slides with one slide of each set attached to said movable transverse means and extending alongside and between the other of said slides parallel thereto which is carried by said body member, scales and indicators arranged on said slides with the scales representing the variables including the roll opening, percentage of reductions, motor speed, and diameter of the rolls with all the scales pertaining to each set of slides constituting together the above named variable factors in one roll stand and coacting to indicate on the various scales the values of the unknown of the above variables in that stand in their proper relation to each other, the other slide of each set of slides carried by the body member having a scale arranged thereon cooperating with an indicator on the corresponding slide of the next succeeding set of slides so that the slides can be successively positioned in the several sets in order that the scales of each set will coact to indicate the values of the above mentioned unknown variables on the scale of the other of said sets of slides which will satisfy all the relations severally embodied in the different sets of slides and of each roll stand, and means carried by said transversely arranged means cooperating with any one of said slides carried by the body member for indicating the rate of speed the sheet is being delivered from the mill train.

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