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MODERN PRACTICE IN ENGINEERING PRODUCT DESIGN OF VARIOUS PRODUCTS SUCH AS INDUSTRIAL MACHINERY, EQUIPMENT AND CONSUMER GOODS 1/

by

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[illegible] Development Organization

MODERN [illegible]

OF VAR[illegible]

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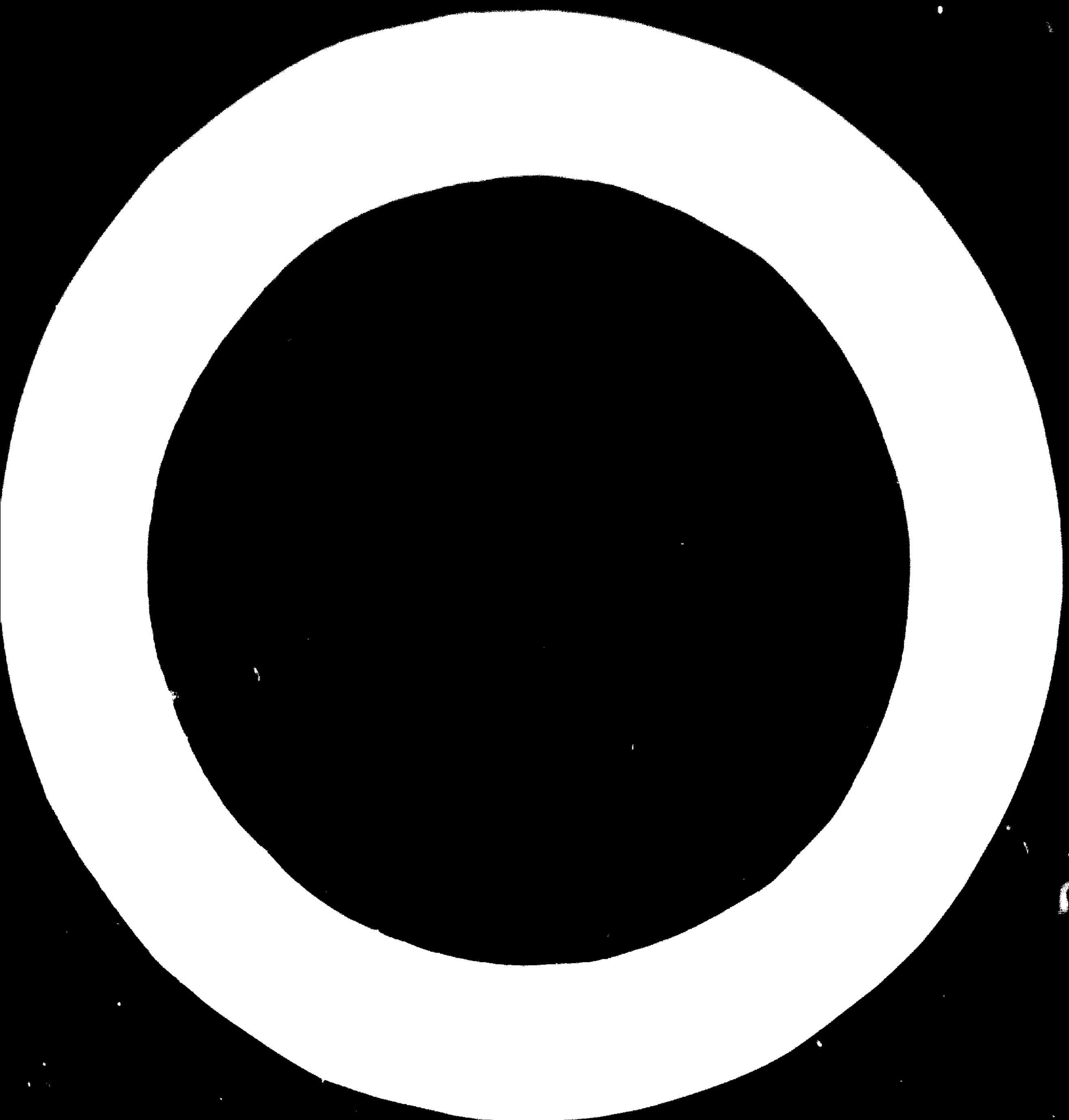


[illegible]

sorting [illegible] Only columns [illegible] are [illegible] for which additional information [illegible] other columns are [illegible] location, type [illegible] trouble [illegible] nature of trouble [illegible] research dept. and engineering dept. The code system [illegible] the various cities and states where customers are located and also so-called [illegible]

[illegible] the [illegible] of a solid [illegible]

[illegible] or no change in the design is required.

[illegible]

[illegible] to obtain [illegible]

[illegible] In the [illegible] steel [illegible], including

[illegible] model

[illegible] for selection [illegible] used for

[illegible] welded [illegible]. Information is further given

[illegible] of the full [illegible] accuracy [illegible]

[illegible]

[illegible] examples refer to the design of ribs for [illegible]. The question is discussed whether the ribs should be vertical and horizontal or at an oblique angle; tests indicated that oblique ribs provide greater rigidity to columns which are torsionally loaded.

An inexpensive test stand for investigating the design of lathe beds is described in detail including results of mathematical derivations and practical tests. (90% reduction for design with bars). Tests for determining the support conditions for transmission shafts are described in detail including sketches, because handbook data were found inadequate under various conditions.

Computer aided design: The latest development in engineering product design is the use of computers. The designer inputs complete input data, the program and the computer delivers a range of results. Among the advantages of the computer - in contrast to the calculating machine - is the fact that the results can be recorded and saved for later use, without repeating the various details. Examples refer to the design of a mechanism for rolling the windows of automobiles up and down, which involves 8000 linkage combinations! This is outlined in detail in the text. Other cases of computer aided design relate to analyzing various tractor designs not only with regard to the mechanical performance but also with regard to the physical reaction of the operator to different design details.

Computers are also used to advantage in the design of components such as gears, bolts, springs, cams, bearings as outlined in detail in the text. The computer can advise t[illegible] designer [illegible]

The [illegible] groups, and [illegible]

data into [illegible] text

<u>Optimization:</u> [illegible]

ty, the [illegible]

adopted. [illegible]

An example for optimization [illegible]

designer must be familiar with [illegible]

production [illegible]

<u>Consumer goods:</u> [illegible] design of [illegible] such as [illegible] bowls, [illegible] regulators, [illegible] strated by sketches and photographic prints. The design starts often with the dimensioning of draw blanks which in turn depends on the material, the [illegible] of the finish part and the machinery available for stamping [illegible] of these products and the different types of machines required [illegible] been established that rent out machinery for the manufacturing of consumer goods. The designer has thus a freer hand in developing various models.

In the design of other goods it is often necessary to take the dimensions of the human body into consideration. Examples are given in the text

<u>Qualifications of the design engineer:</u> In contrast to the designer of non-engineering consumer goods such as clothing, ornaments etc., the design engineer must be familiar with the physical parameters of the material such as tensile strength, hardness etc. and also well trained in design principles and manufacturing methods.

Introduction

Engineering products are usually not placed into production before an exhaustive investigation has taken place covering market analysis, model design, model testing and other items.

In a limited sense the concept of engineering products covers mainly clutches, couplings, bearings, control devices, drives, linkages, springs, seals and similar elements of machinery. In a broader sense, however, an engineering product may be defined as a manufactured article of value and utility to mankind; it is mostly the result of a creative activity. In the following the broader definition of engineering product will be taken as the basis of the discussion.

Market analysis a. General

The starting point for any modern engineering development and design is the analysis of the market for which the resp. product is intended. Without [illegible] of a factory would not know what new designs are needed and expected by the prospective customers; the management would not be able to give the engineering department general instructions and guide lines to follow.

It is usually a modification of existing models which requires the redesign of industrial machinery, equipment and consumer goods, except in cases where an entirely new product is to be developed from the fundamentals up. These cases are rare and often the result of new inventions, although numerous inventions refer also to modifications and improvements of existing engineering products.

As an example, the new designs of automobiles which appear yearly on the market in the United States and in other countries are modifications of last years automobiles, either in style only or in improvements in automatic steering, automatic window opening, new safety devices etc. Another example in the field of industrial machinery is given by the improvements and designs of machine tools, as will be discussed in more details later on in this paper.

Two types of market analysis can be differentiated, namely the general market analysis which is usually of an economic nature and the special market analysis covering the engineering aspects in conjunction with the financial considerations.

The general market analysis deals with problems such as predicting the financial gain that would result from a design change, it covers also the prediction of possible new competition, the new sales effort, advertising, and numerous other subjects which are important to the progress of the company.

About 75% of the American industry uses regularly general market analyses and another 12% employs this method occasionally. Questionnaires are mailed to a representative cross section of the prospective customers or a special agency is employed that reaches a variety of consumers in various parts of the country. If export of the new design is anticipated the market analysis is extended to foreign countries also. The results of the general market analysis are usually reliable, provided that statistical methods are used in the evaluation of the answers received.

b. Special market analysis

Information on the methods employed in a general market analysis is usually given in text books. It is therefore not necessary to go into more details than discussed in the preceding paragraphs. However, outlining of a special market analysis is of great importance in conjunction with the topic of this paper.

Special market analysis often precedes the design of industrial machinery. It shall be discussed in depth with particular reference to the method developed by the author.

The case of machine tools is taken as an example; it refers to the performance of machine tools at the plant of numerous customers of any machine tool builder. The analysis is initiated by preparing a carefully detailed code or recording system which [illegible] up with utilizing the results for design and development of machine tools.

The code system is mostly concerned with complaints coming in from customers because satisfactory and excellent performances are hardly reported by customers, as is human nature. Being alert to complaints and taking care of them keeps a company ahead of competition and renders it possible to improve the product it has to offer.

At first it will be shown how complaints are recorded and analysed in detail and how the results are used to initiate research work and design of industrial machinery.

Punch cards

Punch cards are used for systematically recording the performance of the machine tools in the field. The code system is, of course, rather elaborate and must meet the conditions; it can, however, last for many years.

I B M cards with 80 vertical columns are employed. After punching they are run through a sorting machine in order to determine details of the preformance of the machines. Columns 1 through [illegible] of the IBM are replaced by space for write - in data and instructions; this space is taking up the left half of the IBM card and shown in Table 1 . The right hand portion of the IBM card is used for punching holes, beginning with column 37 up to column 80.

Table 1

Left hand portion of IBM card *)

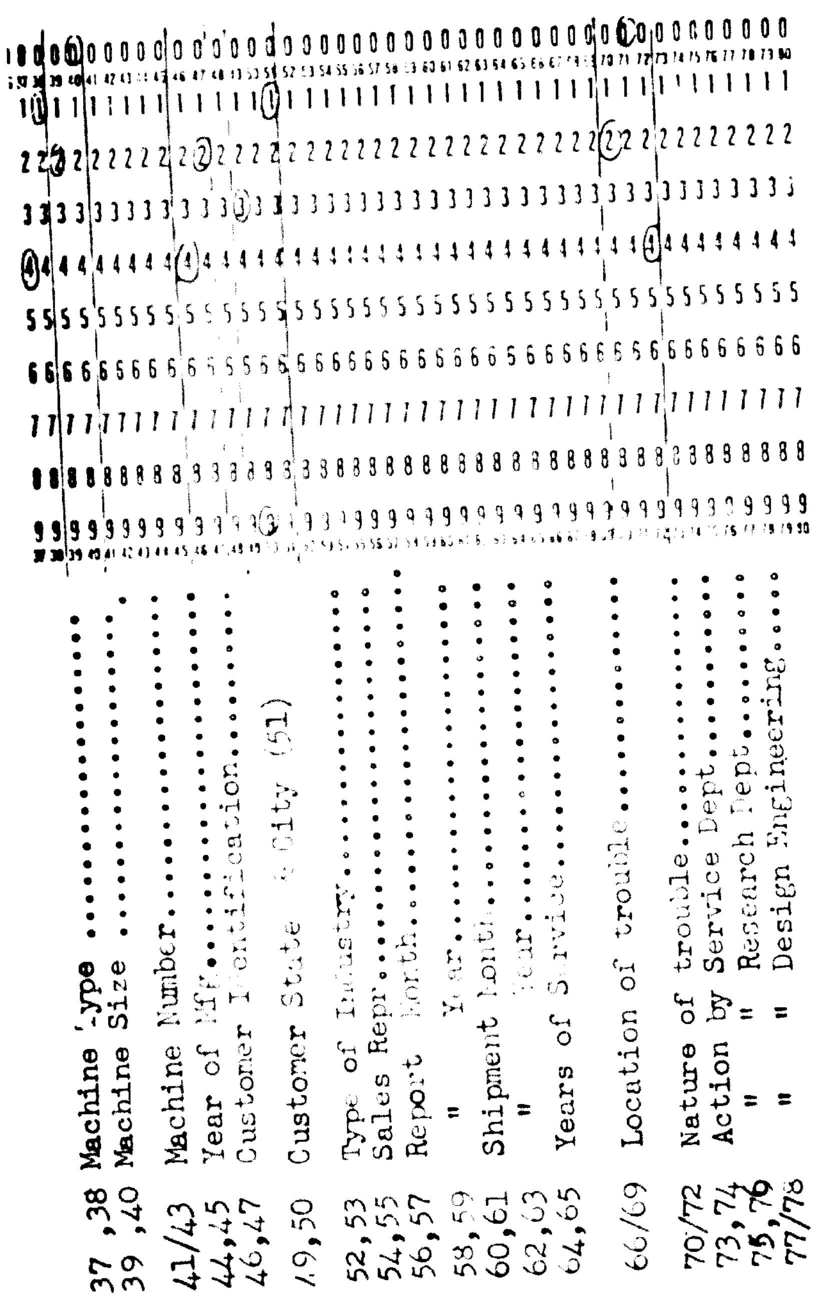
(Write-in space and instruction for punching)

Instructions: punch

Name of machine: Internal Grinder	Hole	Column	Hole	Column	Hole	Column
Machine Type: Chucking Grinder.............	4	37	1	38		
Machine Size: High RPM.....................	2	39	0	40		
Year of Manufacturing: 1960................	6	44	0	45		
Customer Identification: Pilot Corp.	4	46	2	47		
Customer location: Texas...................	3	49	9	50		
Customer location: (City) Waco.............	1	51				
Type of Industry...........................		52		53		
Sales Office...............................		54		55		
Report received		56		57		
Shipment (month)...........................		60		61		
Shipment (year)............................		62		63		
Years of service...........................		64		65		
Location of trouble........................		66		67		68
Nature of trouble: Vibration...............	2	70				
" " " : Finding: loose part......	0	71	4	72		
Action by Service Dept.....................		73		74		
Action by Research Department..............		75		76		
Action by Design Engineering Dept:.........		77		78		

*)Note: Only items of interest with regard to this paper have been marked, by hole number.

On Table 1 the column numbers are printed opposite each item,while the numbers of the holes are written in by the performance recorder. He inserts also additional information as required for reading the card,such as "internal grinder" , "chucking grinder " ,"high RPM " ,"Pilot Corp." and others. The card is then forwarded to the punch operator who punches the holes in the right hand portion of the IBM card according to the instructions given him by the performance recorder at the left hand portion of the card. The right hand portion with example for the punched holes is given by Table 2.



The codes comprise numerous pages and are given here in abstract.On pages 7....11 the code system for "Machine Type and Machine Size " will be found. Columns 37 ... 40 are reserved for them.

In detail,it will be seen that Boring Mills and Machines (page 7) are always indicated by hole " 0" in column 37. A "0" in column 38 signifies together with the " 0 " hole in column 37 "Horizontal Boring Mills and Machines". Correspondingly a " 1 " hole in column 38 refers to vertical boring machines , a " 2 " hole in this column applies to precision boring machines . Columns 39 and 40 give information on the size of the machines. As an example, hole 1 in column 39 and hole 2 in column 40 refer together to Floor type machines over 5" .... 8" diameter of the bar. Punching 0012 in columns 37,38,39 and 40 indicates therefore a horizontal boring mill ,floor type with over 5" to 8" diameter of bar.

The code system for gear machinery is outlined on page 8,again for punching columns 37 ... 40.All gear machines begin with numeral "3", grinding machines begin with " 4 " .Chucking grinders with high RPM have the code number 4120. (page 9) .Page 10 refers to lathes (in ab - stract) , and page 11 to milling machines (in abstract).

Drilling machines start with number 2 (not included here) planers with Nr. 7 , saws with Nr. 8, sheet metal machinery with Nr. 9.

The example given on Tables 1 and 2 refers to a chucking grinder (code 41) with high RPM (code 20) .Some of the items written in by the performance recorder (left hand side of the IBM card) are selfexplanatory,such as year of manufacturing, machine number , and others and shall therefore not be discussed here.

The customer is identfied by the first two letters of the company name as indicated by code for columns 46 and 47 (page 12).

0	BORING MILLS AND MACHINES	Punch holes in columns 37-38-39- 40
00	Horizontal Boring Mills	
	Table Type, under 3" diameter of bar	0000
	" " , 3" to 5" " " "	0001
	" " , over 5" to 8 " " "	0002
	" " , over 8" " " "	0003
	Floor Type, under 3" diameter of bar	001o
	" " , 3" to 5" " " "	0011
	" " , over 5" to 8" " "	0012
	" " , over 8" " " "	0013
	Planer Type	0020
01	Vertical Boring Mills, incl. vertical turret lathes	
	Swing 24" to 36"	0100
	" over 36" to 54"	0101
	" " 54" to 72"	0102
	" " 72" to 12o"	0103
	" " 10 ft	0104
02	Precision Boring Machines, horizontal	
	Single end	0200
	Double end	0201
	Special	0202
03	Jig Borers	
	up to 15" table travel	0300
	over 15" to 3o" "	0301
	" 3o" to 45" "	0302
	" 45" "	0303
09	Boring Mills and Machines, not otherwise classified(Rifle working machines etc.)	0900

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GEAR MACHINERY

In columns 37-38-39-40 punch holes:

30 Gear Hobbers

under 4" max. diameter	3000
over 4" to 12" "	3010
" 12" " 24" "	3020
" 24" " 48" "	3030
" 48" "	3040

31 Gear Shapers (spur, helical, external, internal)

Fellows type 7	3100
" " 7 A	3110
" " 6	3120
" " 6 A	3130
" all other types	3140
Sykes and other makes	3150

32 Bevel Gear Machines

all sizes	3200

33 Rack- and Gear Cutters

all sizes	3300

34 Gear Shaving Machines

all sizes	3400

35 Gear Grinders and Lappers

all sizes	3500

39 Misc. Gear Machinery

(incl. spline hobbers, but not spline millers see milling machines. Not including generators for threads, see thread millers)	3900

4 GRINDING MACHINES INCL. LAPPING AND HONING MACHINES

In Columns 37-38-39-40 punch holes :

40 **External, plain cylindrical**

up to 6" swing	4000
over 6" to 10" swing	4001
" 10" to 20" "	4002
" 20" to 40" "	4003
" 40" "	4004

External, universal cylindrical

up to 6" swing	4010
over 6" to 10" swing	4011
" 10" to 20" "	4012
" 20" to 40" "	4013
" 40" "	4014

41 **Internal, cylindrical, plain or chucking**

Heald 70	4100
" 72	4101
" 81	4102
" others	4109
Bryant 16	4110
" 24	4111
" others	4119
Chucking Grinders, high RPM	4120
Other internal grinders	4190

42 **Centerless Grinders**

external, all sizes	4200
internal, " "	4201

43 **Surface Grinders, rotary table**

horizontal, 8 to 15" chuck diam.	4300
" 16" and over	4301
vertical , 16" to 26" chuck diam.	4310
" 27" and over	4311

Surface Grinders, reciprocating table

horizontal, up to 18" table travel	4320
" over 18" to 30" " "	4321
" " 30" to 60" " "	4322
" " 60" " "	4323
vertical , up to 18" " "	4330
" over 18" to 30" " "	4331
" " 30" to 60" " "	4332
" " 60" " "	4333

continued

5 **LATHES**

In Columns 37, 38, 39, 40 punch holes:

50 Engine and Tool Room Lathes

up to 12" swing, and up to 30" center distance	5000
" " " " more than " " "	5001
more than 12" to 16" swing, up to 48" center distance	5010
" " " " " " , more than 48" center distance	5011
" " 16" " 20" " , up to 48" center distance	5020
" " " " " " , more than 48" center distance	5021
" " 20" " 27" " , up to 60" center distance	5030
" " " " " " , more than 60" center distance	5031
" " 27" " 48" " , up to 96" center distance	5040
" " " " " " , more than 96" center distance	5041
" " 48" swing all center distances	5050

51 Gap Lathes

up to 24" swing	5100
over " "	5101

52 Bench Type Lathes

all sizes	5200

53 Turret Lathes, Ram Type (Vertical Turret Lathes=Vert. Boring Mills)

Round Bar Capacity	W & S,	Gisholt, Model #	J & L,	B & O	
Under 1"	1			1	5301
1"	2			2	5302
1½"	3	3	3	3	5303
1 3/4" and 2"	4	4	4	4	5304
2½"	5	5	5	5	5305
over 2½"				7	5306

Turret Lathes, Saddle Type

up to 2½"	1A	1L	7A, 7B	21	5311
3" and 3½"	2A	2L	8A, 8B	21 and 22	5312
4½" and 6"	3A	3L		22	5313
over 6"	4A	4L, 5L			5314

54 Automatic Chucking Machines, Single Spindle

Baird	5400
Cleveland	5401
Foster-Gisholt (Fastermatic)	5402
New Britain	5403
Potter & Johnston	5404
Warner & Swasey	5405
Others	5406

(over)

MILLING MACHINES

In Columns 37, 38, 39, 40 punch holes:

60 **Plain, Horizontal Knee Type Millers**

# 1	(less than 28" table travel)	6001
# 2	(28" table travel and up)	6002
# 3	(34" " " " ")	6003
# 4	(42" " " " ")	6004
# 5	(50" " " " ")	6005

Universal, Horizontal Knee Type Millers

# 0	(Screw feed types)	6010
# 1	(table travel as above)	6011
# 2	(" " " ")	6012
# 3	(" " " ")	6013
# 4	(" " " ")	6014
# 5	(" " " ")	6015

Vertical Knee Type Millers

# 1	(table travel as above)	6021
# 2	(" " " ")	6022
# 3	(" " " ")	6023
# 4	(" " " ")	6024
# 5	(" " " ")	6025

61 **Automatic Knee Type Millers ("Production Millers")**

Cincinnati 1 - 12 and 1 - 18 types	6100
Kearney & Trecker	6101
Others	6102

62 **Simplex Bed Type Millers (Hydromatics)**

Table travel less than 6"	6200
" " over 6" to 12"	6201
" " " 12" to 24"	6202
" " " 24" to 48"	6203
" " " 48" to 72"	6204
" " " 72	6205

Duplex Bed Type Millers (Hydromatics)

table travel less than 30"	6210
" " over 30" to 48"	6211
" " " 48" to 72"	6212
" " " 72"	6213

63 **Other Bed Type Millers**

Cincinnati Type 2 - 18 and 2 - 24 with and without Rise and Fall	6300
Cincinnati Type 0 - 8	6310
other makes	6320

continued

(Abstract from)
Code System for Customer
Identification

Columns 46 and 47

Punch Nr*)	Names beginning with	Punch Nr*)	Names beginning with
00	Aa - Ai	01	Aj - Ar
02	As - Az	03	Ba - Bh
04	Bi - Bq	05	Br - Bz
06	Ca - Ch	07	Ci - Cr
08	Cs - Cz	09	Da - Dh
10	Di - Dr	11	Ds - Dz
12	Ea - Eh	13	Ei - Er
14	Es - Ez	15	Fa - Fi
16	Fj - Fr	17	Fs - Fz
18	Ga - Gi	19	Gj - Gr
20	Gs - Gz	21	Ha - Hh
22	Hi - Hr	23	Hs - Hz
24	Ia - Iz	25	Ja - Jz
26	Ka - Kh	27	Ki - Kr
28	Ks - Kz	29	La - Lh
30	Li - Lr	31	Ls - Lz
32	Ma - Me	33	Mf - Mr
34	Ms - Mz	35	Na - Nh
36	Ni - Nr	37	Ns - Nz
38	Oa - Oe	39	Of - Or
40	Os - Oz	41	Pa - Ph
42	Pi - Pr	43	Ps - Pz
44	Qa - Qz	45	Ra - Rh
46	Ri - Rr	47	Rs - Rz
48	Sa - Se	49	Sf - Sr
50	Ss - Sz	51	Ta - Th **)
52	Ti - Tr	53	Ts - Tz
54	Ua - Uk	55	Ul - Uz
56	Va - Vk	57	Vl - Vz
58	Wa - Wh	59	Wi - Wr
60	Ws - Wz	61	Xa - Xz
62	Ya - Yz	63	Za - Zz

*) The first number is to be punched in column 46, the second in column 47
**) Omit "The" in company names. Column 48 is left open for later subdividing

In addition, the location of a customers plant is used for identification. First by states (or nations), punching columns 49 and 50 and then by cities or districts (column 51) as outlined by a number of example codes on pages 14 to 16.

The other items to be punched (columns 52 through 65, see Table [illegible] on page 5) are generally not of interest to the designer and therefore not discussed here in detail.

The location of trouble is, of course, of importance and four columns are reserved for recording it (columns 66... 69). Taking as an example the design of lathes into consideration the following hole numbers are assigned to column 66:

	Punch hole in Column 66
Headstock and transmission	0
Apron, Quick Change Box	1
Back box, electr. control	2
Carriage, Tool Post	3
Tailstock	4
Bed, pan, legs	5
Motor drive	6
Attachments	7
N/C	8
Other parts	9

The further subdivision of part location is indicated by punching columns 67, 68 and 69 and supplemented by so called "exploded" sketches showing the parts with their code number. On page 17 is shown the exploded sketch for the back box and the electrical control comprising 34 different parts with code number 305 ..339. Another example (page 18) deals with a taper attachment and code numbers.

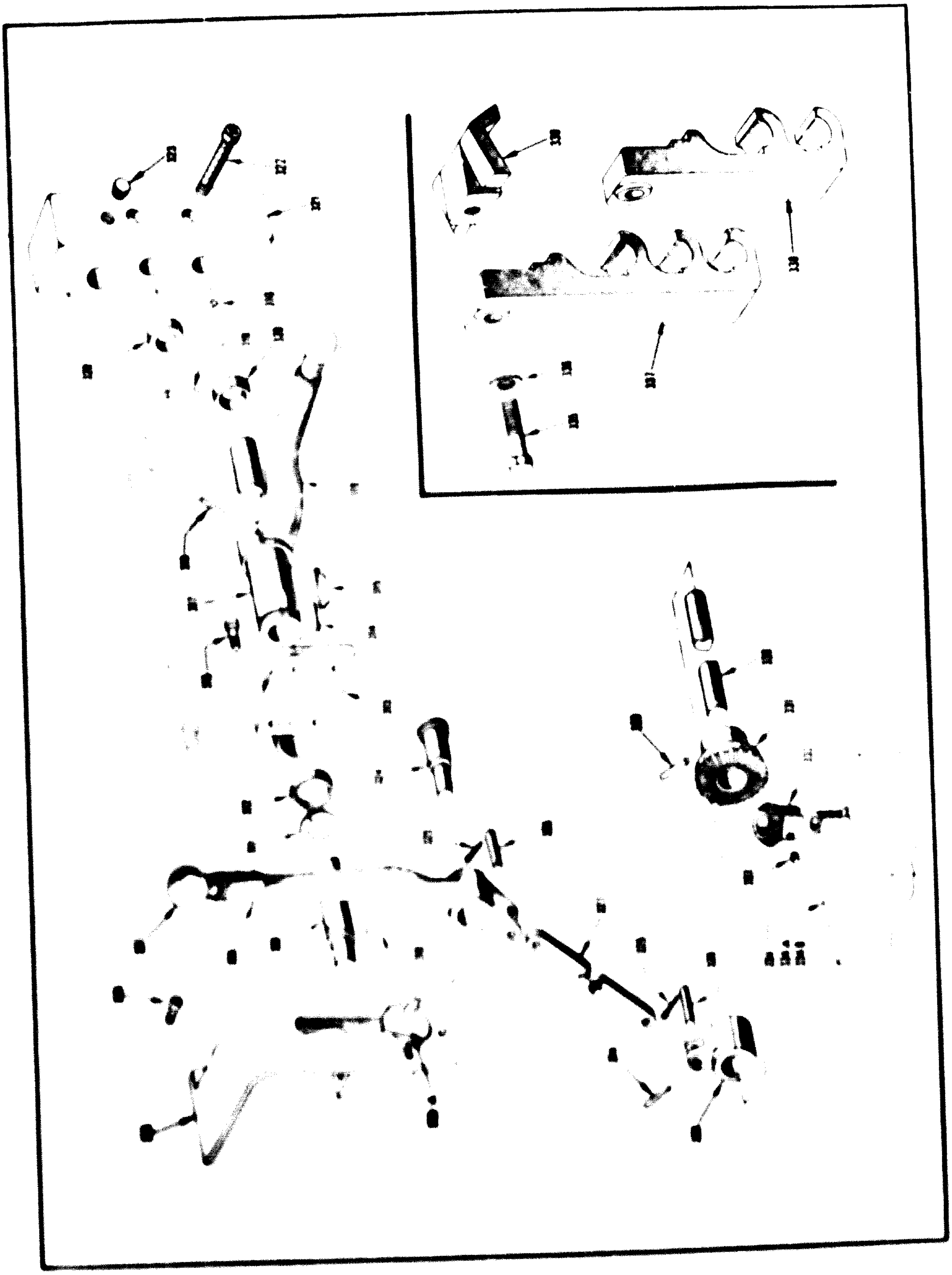
In Columns 4,5,6 punch holes

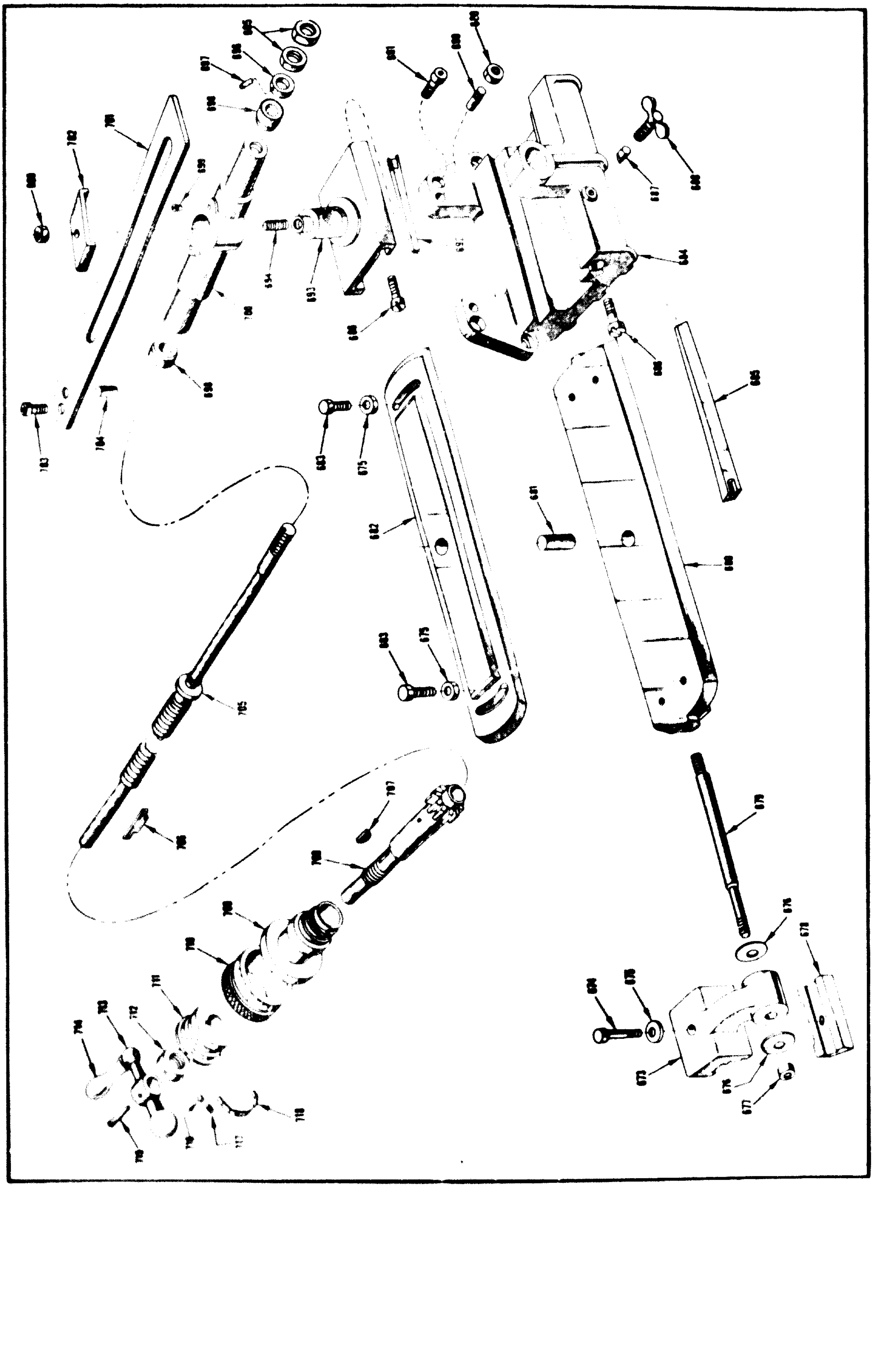
State	City or District	
Alabama	entire state	[illegible]
Arizona	" "	45
Arkansas	" "	33
California	" "	40
	Berkeley	492
	Fresno	493
	Glendale	494
	Long Beach	494
	Los Angeles	494
	Oakland	492
	Pasadena	494
	Sacramento	492
	San Diego	494
	San Francisco	492
	San Jose	492
	Santa Monica	494
	Stockton	492
Canada	entire state	60
Colorado	" "	42
Connecticut	" "	11
	Bridgeport	114
	Bristol	113
	East Hartford	114
	Fairfield	113
	Hamden	114
	Hartford	113
	New Britain	113
	New Haven	114
	New London	112
	Norwalk	114
	Stamford	114
	Stratford	114
	Waterbury	114
	West Hartford	113
	West Haven	114
Delaware	entire state (incl. New Jersey)	13
District of Columbia	incl. Maryland and incl. Alexandria City Va. Arlington county, Fairfax county Va.	20
Florida	entire state	27
Georgia	" "	26

In Columns [illegible], punch holes:

State	City or District	
Louisiana	entire state	34
Maine	" "	01
Maryland	entire state incl. District of Columbia	20
Massachusetts	entire state incl. Rhode Island	10
	Boston	101
	Brockton	101
	Cambridge	101
	Fall River	102
	Holyoke	104
	Lawrence	101
	Lynn	101
	Malden	101
	Medford	101
	New Bedford	102
	Quincy	101
	Pittsfield	104
	Springfield	104
	Worcester	103
Michigan	entire state	16
	Allen Park	160
	Alpena	161
	Dearborn	160
	Detroit	160
	Ecorse	160
	Flint	162
	Grand Rapids	164
	Highland Park	160
	Kalamazoo	164
	Lansing	162
	Lincoln Park	160
	Muskegon	164
	Pontiac	160
	River Rouge	160
	Saginaw	162
	Wayne	160
	Wyandotte	160
Minnesota	entire state	30
	Duluth	301
	Minneapolis-St.Paul	302
	Rochester	302
Mississippi	entire state	29

State	City or District	In Columns 49,50,51 punch holes:
Texas	entire state	39
	Amarillo	393
	Austin	392
	Beaumont	392
	Corpus Christi	392
	Dallas	391
	El Paso	394
	Fort Worth	391
	Galveston	392
	Houston	392
	San Antonio	392
	Waco	391
	Wichita Falls	391
Utah	entire state (incl. Arizona)	45
Vermont	" "	03
Virginia	entire state	21
	Alexandria (see District of Columbia)	20
	Arlington County (see Distr. of Columbia)	20
	Fairfax " (" " " ")	20
Washington	entire state	46
West Virginia	" "	22
	Charleston	224
	Huntington	224
	Wheeling (incl. Brooke, Hancock, Marshall and Ohio Counties) see Steubenville O.	152
Wisconsin	entire state	19
	Fond du Lac	192
	Green Bay	191
	Madison	192
	Milwaukee	192
	Racine	192
Wyoming	entire state	43





The nature of machine trouble is likewise of great interest to the designer. It is determined by a member of the service department .He is dispatched by the builder to the customer in case of unsatisfactory machine performance and is usually able to correct such trouble on the spot. However, in order to learn from experience, the service man's report is send to the performance recorder and columns 70.... 72 are punched with the pertinent information .

In column 70 (page 20) the nature of the malfunctioning of the machine is recorded,such as (hole 2 in column 70) :Heat- Vibration - Noise. Mechanical failures have hole " 0 " punched in column 71 and hole 4 in column 72 when parts worked loose. Hydraulic failures have hole 1 punched in column 71, electric trouble is marked by punching hole 2 in column 71 etc. (page 21)

Failures caused by improper handling of the machine are indicated by hole 5 in column 71 (page 22) . Insufficient training of the operator is thus indicated by 51 , overloading of the machine by 52 (columns 71,72) etc.

Evaluation of the special market analysis

Every month or three months - as the case may be determined by Management-, the market analysis department runs the IBM cards through the sorting machines. In this way the frequency of troubles can be determined in great detail and graphs can be prepared giving a survey of the complaints adapted to the requirements of the resp. departments such as management, engineering, sales, production etc.

Figure 1 (page 23)gives an example for the performance records of machine tools of a builder of various types of boring mills,broaching machines,lathes,grinders etc.

Code for "Nature of trouble"

Customer's Complaint

Column 70 Punch Nr.	Nature of complaint
0	Quantity not satisfactory; required output not obtained
1	Quality not satisfactory;required work dimension or accuracy not obtained
2	Vibration - Noise - Heat
3	Oil leaks out; coolant leaks in
4	Scoring of slides
5	Sluggish travel; stalling; overrun;
6	Machine break down,cannot be operated
7	Inconvenient or unsafe to operate;difficult to clean
8	Poor workmanship;poor design; shipping error; damage in transport
9	Other,incl. insufficient information

Service Department's Findings

Columns 71,72 Punch Nrs.	Nature of Finding
(0)	Mechanical failures due to:
00	Porous casting
01	Part broken or cracked
02	" pick up ,bent
03	" has incorrect dimensions
04	" worked loose,was dislocated; chains stretched
05	" too tight
06	" missing, wrong
07	" rusty, dirty
08	Interference, run out, misalignment ,poor engagement
09	Miscellaneous others

continued

Service Department's Findings
(continued)

Columns 71,72 Punch Nrs.	Nature of Findings
(1)	Hydraulic Failures due to:
10	Spring failure in valve
11	Pump failure
12	Plunger loose
13	Pressure incorrect
14	Pipe clogging; rusty or dirty fluid
15	Valve sticking
16	Connections loose
17	Improper drainage
18	Sealing, gasket failure
19	other hydraulic failures
(2)	Electric Failure due to:
21	Incorrect wiring
22	Electr. equipment undersize
23	Insulation damage
24	Fuse burned out
25	Short circuit
26 - 28	.... (open for later recording)
29	other electric failures.
(3)	Lubrication Failures due to:
31	Spring failure in lubrication valve
32	Lubrication pump failure
33	Line pressure incorrect
34	Rusty or dirty oil
35	Valve sticking
36 - 38	..... (open for later recording)
39	Other lubrication failures

continued

Service Department Findings
(continued)

Columns 71,72 Punch Nrs.	Nature of Findings:
(4)	Failures in the coolant system
41..49	same subdivisions as in code for lubrication failures
(5)	Failures due to improper handling of machine
51	Insufficient training of operator
52	Overloading of machine (broken gears, clutches etc)
53	Incorrect setting of adjustment dogs
54	Incorrect gib adjustment
55	Incorrect feed,speed ,tool geometry
56	Poor guide way protection
57	Machine not kept clean
58	Chips accumulate on machine
59	Other items(caused by improper handling of machine)
(6)	Special Items
61	Shipping error
62	Poor painting of machine
63	Bearing trouble
64	Machine out of level
65	Incorrect N/C tape
66	Worn belt
67	Floor vibration
68	Attachment used not of company's design
69	Nothing wrong

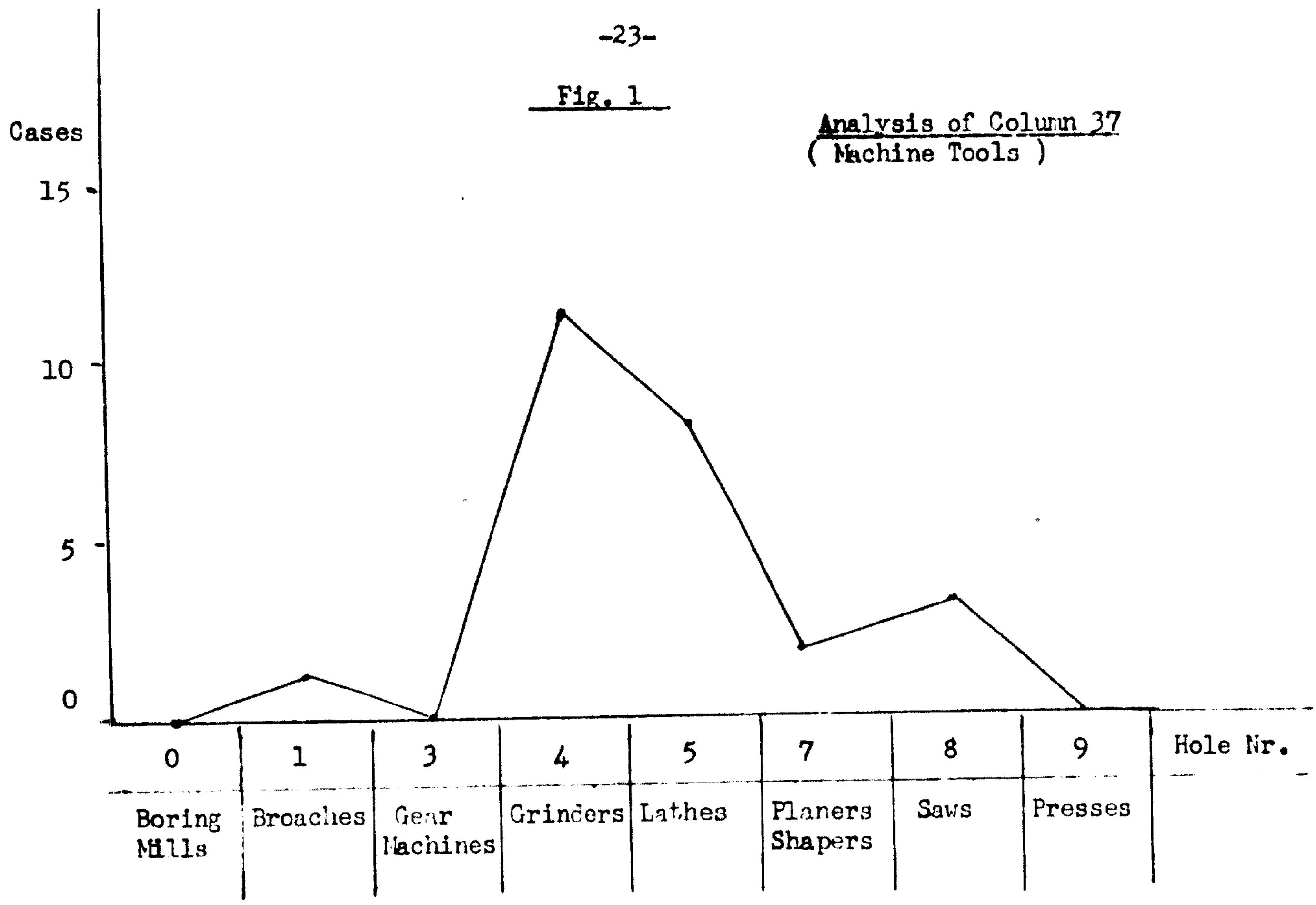


Fig. 1
Analysis of Column 37
(Machine Tools)
Cases
15
10
5
0
0
Boring Mills
1
Broaches
3
Gear Machines
4
Grinders
5
Lathes
7
Planers Shapers
8
Saws
9
Presses
Hole Nr.

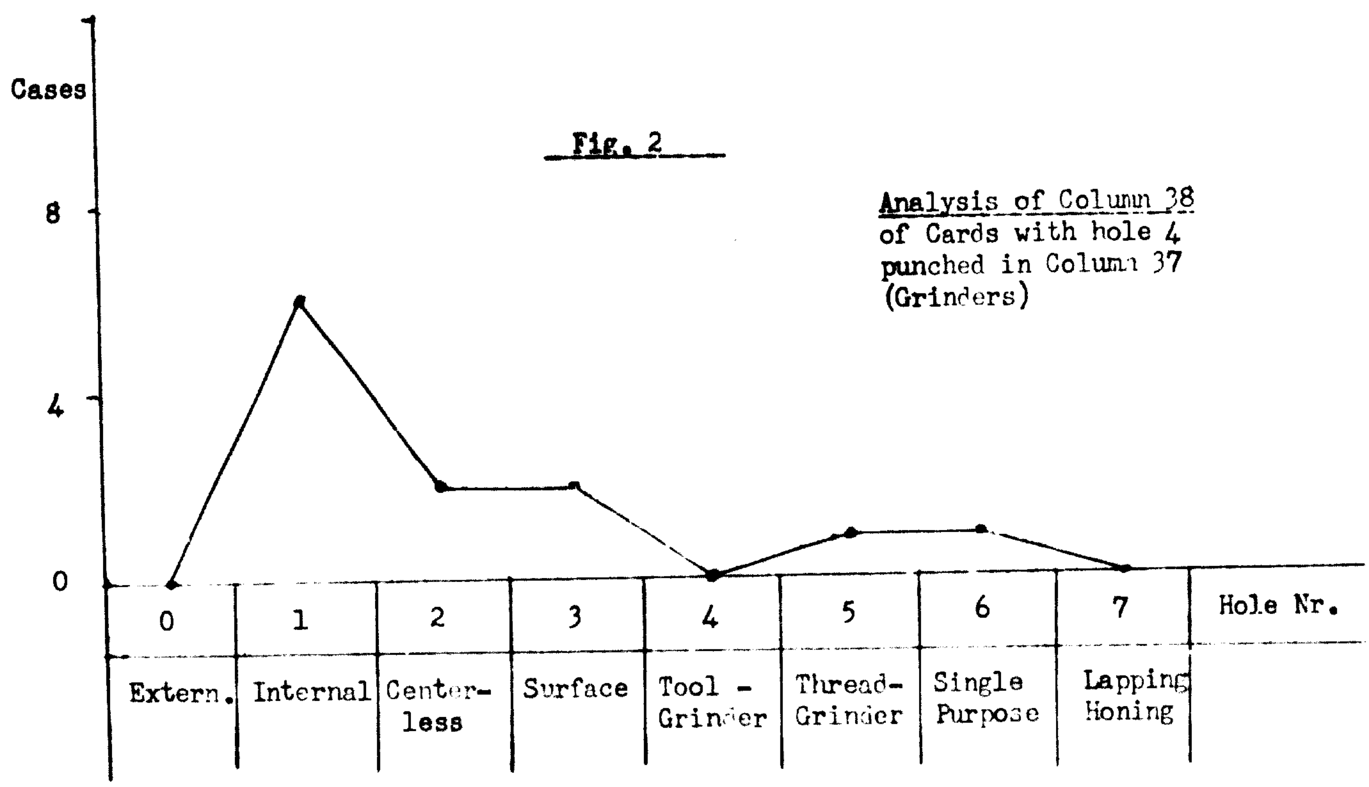


Fig. 2
Analysis of Column 38
of Cards with hole 4
punched in Column 37
(Grinders)
Cases
8
4
0
0
Extern.
1
Internal
2
Center-less
3
Surface
4
Tool - Grinder
5
Thread-Grinder
6
Single Purpose
7
Lapping Honing
Hole Nr.

From Fig. 1 management will notice the relatively great number of complaints on grinding machines, although the number may be only a small percentage of the total number of machines built. However, when this trend is noticed over a certain period of time, it will order a further break down of the information, namely an analysis of the cards with hole 4 punched in column 37. The result is shown by Fig.2 indicating that the internal grinders contributed greatly to the reported trouble, and among them the chucking grinders with high spindle speeds.

Management will thus have the cards analysed with regard to the nature of the trouble (columns 70...72) and conclude that a redesign of the machine is economically justified. The first step being an instruction to the research department to investigate the case and to propose, in cooperation with the engineering design department, changes in the design or an entirely new design.

Design prognosis by model tests

Having received the order from management to proceed with developing a new design, the research and the engineering departments begin to discuss a general lay-out . The actual design is preceded by the testing of a model in the research department .These models are usually made at a reduced scale and analyzed with regard to the desired specifications, giving the designer definite data for the design and often alternate solutions.

The reason for making a model is to predict characteristics of the full size structure. Certain basic rules must be observed in order to obtain a realistic relation between model and machine, as shall be shown by the following example.

Assume that management wants to find out whether a steel welded bed of a high speed chucking grinder with up to 100 000 RPM would give satisfactory performance ,namely higher accuracy than other types and freedom from vibration. The research director decides to build a half scale model of the bed in aluminum. He has selected aluminum in order to obtain a simple mathematical relationship between the vibration of model and steel bed.

The relationship can be determined by dimensional analysis (see ref 1 at end of paper for further details) as follows:

Let E_m and E_b = modulus of elasticity of aluminium model (index "m") and of the steel bed (index "b")

" I_m " I_b = moment of inertia of model and bed respectively

" M_m " M_b = mass of model and bed respectively, namely

$$M = \text{volume} . \text{density} / 386$$

L_m and L_b = length dimension of model and bed respectively

$r = L_m/L_b$ = ratio of length dimensions which represents the reduction in linear size of the model with regard to the actual structure.

The natural frequency of vibration follows from :

$$w = \text{const.} \sqrt{\frac{E \cdot I}{M \cdot L^3}} \qquad (1$$

where the constant refers to the end conditions ,such as hinged, clamped, etc.

The ratio of the natural frequencies of model and steel bed is therefore:

$$w_m / w_b = \sqrt{\frac{E_m \cdot I_m \cdot L_b^3 \cdot M_b}{E_b \cdot I_b \cdot L_m^3 \cdot M_m}} \qquad (2$$

Using aluminum for the model and steel for the full bed ,with $E_m = 10 \cdot 10^6$ and $E_b = 30 \cdot 10^6$, the ratio $E_m/E_b = 1/3$. The ratio of the moment of inertia is proportional to the fourth power of the length ratio, hence $I_m/I_b = r^4$. With the density 0.096 (aluminium) and 0.288 (steel) the ratio of the masses follows from $M_m/M_b = (L_m/L_b)^3 \cdot 0.096/0.288 = r^3/3$. Substituting these data into eq. 2 yields :

$$w_m/w_b = \sqrt{\frac{r^4 \cdot 3}{3 \cdot r^3 \cdot r^3}} = 1/r \qquad (3$$

Eq. 3 indicates that the ratio of the natural frequencies of model and bed is inversely proportional to the ratio of their length dimension .Hence when the aluminum model is half the size of the bed (that is when $r = \frac{1}{2}$) the natural frequency of the model must be twice that of the steel bed for equal performance . In this way is it possible to investigate the design before a machine has been built.

The intensity of vibration can be kept low (according to Figure 3) by rigid design and by introduction of damping,i.e. by designing "left" of

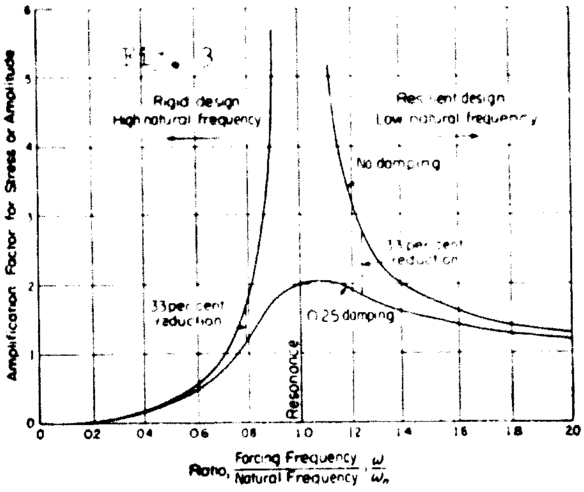
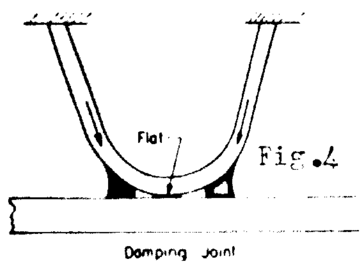


Fig. 3
Rigid design
High natural frequency
Resilient design
Low natural frequency
No damping
33 per cent reduction
33 per cent reduction
0.25 damping
Resonance
Amplification Factor for Stress or Amplitude
Ratio, Forcing Frequency / Natural Frequency, ω/ωn


Flat
Fig.4
Damping joint

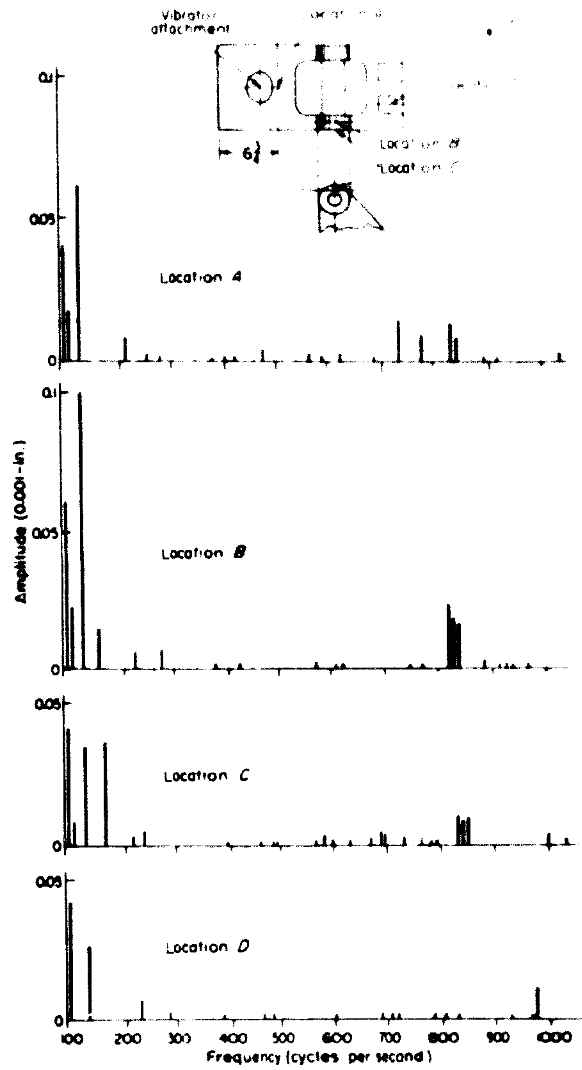
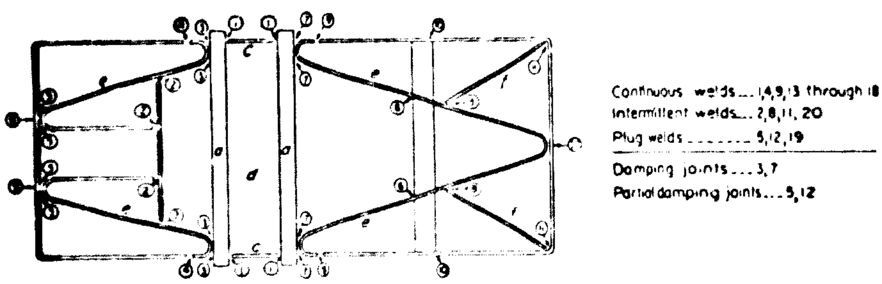
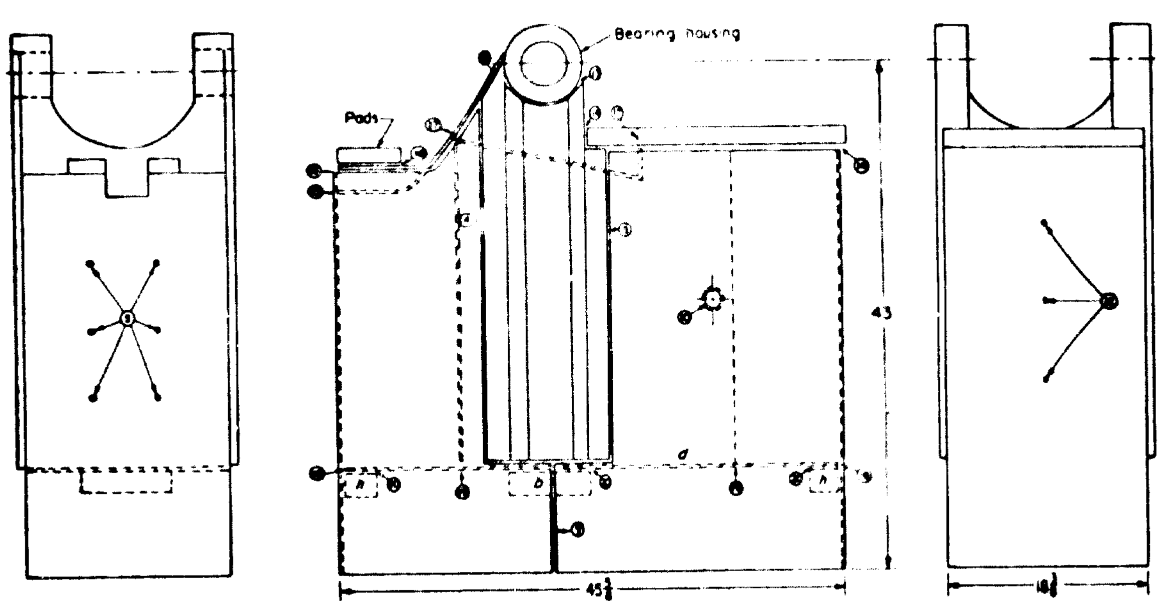

Vibrator attachment
Location A
Location B
Location C
Location D
Amplitude (0.001-in.)
Frequency (cycles per second)

Fig. 6


Continuous welds ... 1,4,9,13 through 18
Intermittent welds ... 2,8,11,20
Plug welds 5,12,19
Damping joints ... 3,7
Partial damping joints ... 5,12


Bearing housing
Pads
43
45¾
18⅞

resonance.

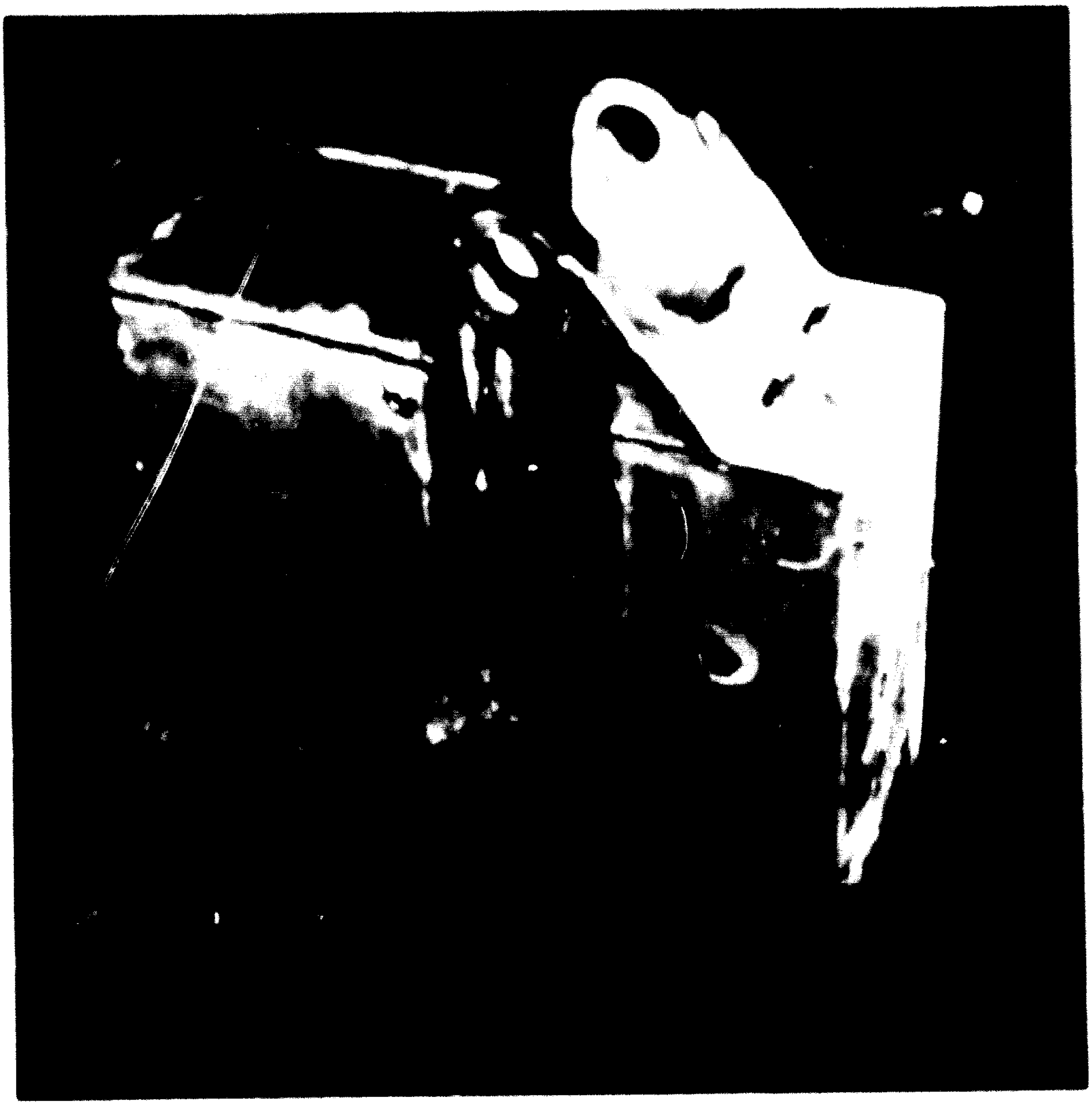
The design technique involves the use of damping joints explained by Fig. 4 (page 27). They require a particular welding technique. V-shaped or U-shaped ribs, channels or similar structural shapes are so arranged that the welding produces stresses as indicated by the arrows, damping increased by utilizing use of the friction at the junction of two members and filling a fillet on the radius of the bend.

The half scale aluminum model is shown in Fig. 7 (page 29a) and a plastic model in Fig. 8 .(page 29b) It served to better visualize the ribbing system adopted for the design. It will be realized that this design permits a "closed box arrangement" with no openings, thus strengthening the structure particularly with regard to torsional loads.

Results of the vibration tests will be seen from Fig. 5 (page 27), where also the location of the vibrator attachment is indicated. According to the previous analysis, it was necessary to test the aluminum model up to 2 x 1670 cps = 3340 cps in order to cover the entire working range of the actual machine (100 000 RPM = 1670 cps). The amplitudes measured on the model were very small except in the neighborhood of about 150 cps. It was found by later tests that this disturbance was due to the frame of the vibrator support and not inherent in the design. Hence it could be stated that the design of the new structure would be vibration-free up to 100 000 RPM.

The welding sequence of the design is indicated by the numbers of Fig. 6 Page 27.

A comparison of the old design and the new one is presented by Fig. 9 (Page 30) The surface finish improved from an average of 16 μm to an average of 8.5 μm; the dimensional accuracy from 67 μm to 15.7 μm. Grinding time was reduced from 12 s to 2½ s, well justifying the effort.



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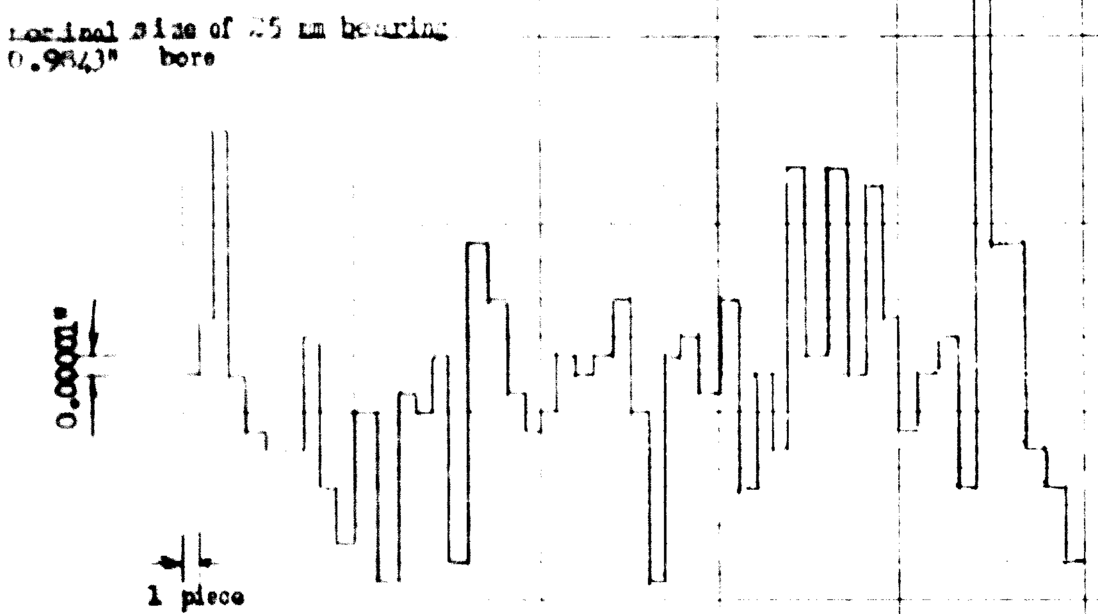
Comparison of performance (old vs. new machine)

Accuracy tests.

Grinding New Departure 3205 Inner Ring
52100 Steel ; 64 Rockwell C

Fig. 9

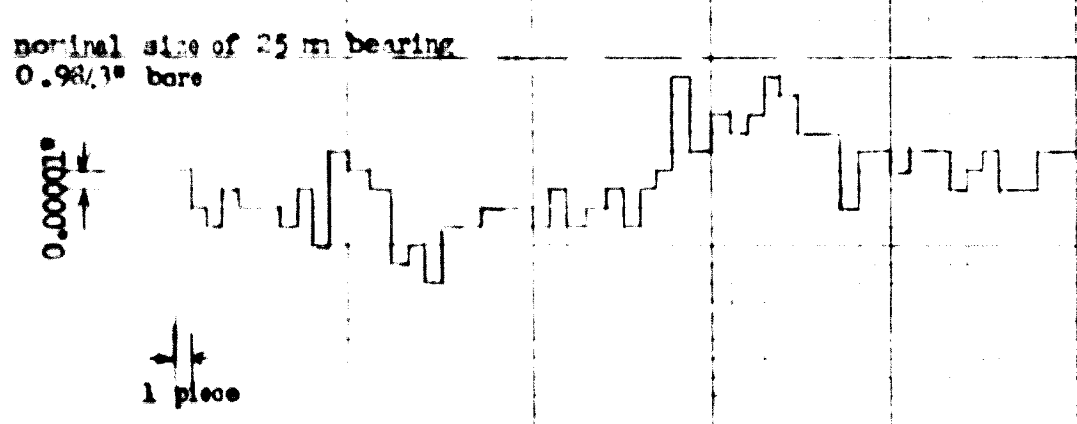


On
Old machine:

Surface Finish= 16 μ" R.M.S

Average dimensional variation 67 μ"

50 pieces ground at 12 sec. rough and 6 sec. finish; A 80 K 5 VBE wheel ; 3/4"dia.
30 000 RPM. Coolant Lusol 1:40; cam feed; rough dwell = 5 sec. ;work speed = 1200 RPM



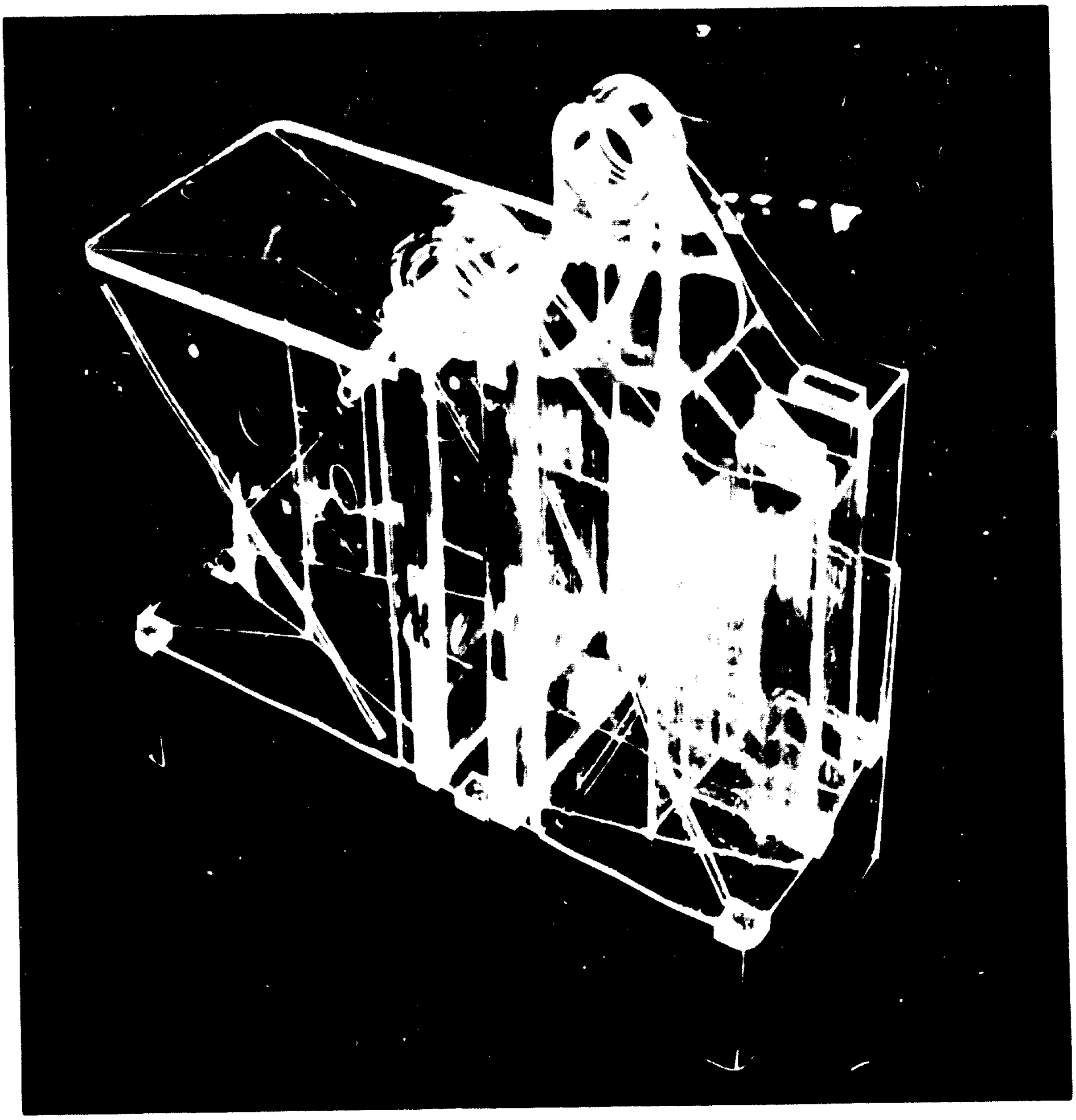
On
New machine:

Surface finish 8.5 μ" R.M.S

Average dimensional variation 15.7 μ"

50 pieces ground at 2½ sec.rough and 3 sec. finish;19 A 80 M6 VG wheel; 3/4" dia;
30 000 RPM. Coolant Lusol 1:40; 23 # feed pressure; rough dwell = 0 sec;work = 1200 RPM

Fig. 8



Transparent mo el for ri bing esign study
(¼ natural size)

Examples for the design of milling machine parts

Except in cases of routine design changes or of designs of minor significance the design department depends on the findings of the research department if no data are available or if comparison between several possible solutions is desired.

Several examples involving machine elements shall be discussed now. The question was asked when designing a knee type milling machine whether the ribbing on the inside walls of the column should be vertically arranged as shown in Fig.10 (Page 32a) or at an angle as shown in Fig.11 (Page 32a). A model was developed (Fig. 15, Page 32 b) and subjected to torques of different magnitude . The deformation was measured at numerous places as indicated in Fig. 15 (Page 32 b) .The data refer to μ. The torque at "A" und "B" represents the forces generated by the feed in a milling operation. It was found that ribs running at 45° (Fig. 10 page 32a) are more effective than the customary vertical and horizontal arrangement .This applies to cases where the machine column is substantially under torque.

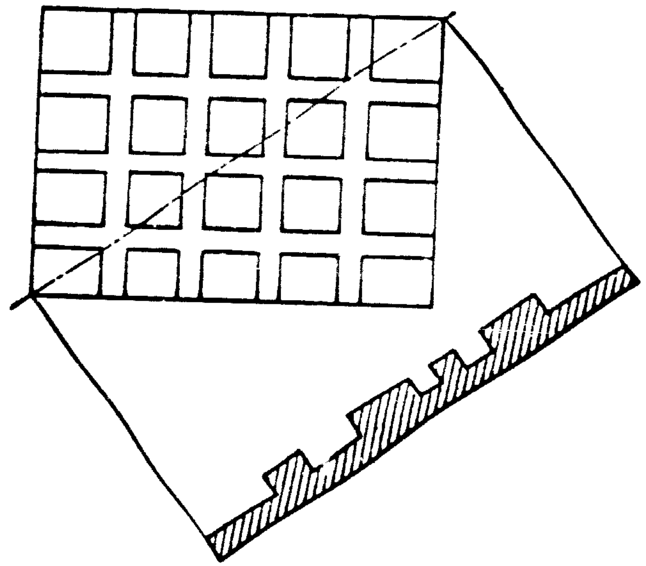
Another example for cases where more than one solution must be taken into consideration in the design of guideways for the knee of a milling machine is given by Figs. 12 and 13 on Page 32a. The problem was to determine whether the Reaction Forces could become zero and thus prevent a satisfactory guide and freedom from vibration.

With the dimensions indicated on Figs. 12 and 13 the reaction forces are as follows (Table 3):

Table 3

Design Fig.	Reaction A	Reaction B	Reaction D
12	$(e - L/2) . P_V/a$	$\sin 45^\circ (e+a-L/2) . P_V/a$	$\sin 45^\circ (e-a-L/2) . P_V/a$
React.=0 when:	$e = L/2$	$e = L/2 - a$	$e = L/2 + a$
13	$(2e + H)/(2a + L + W)$	same as for A	P_V

Fig. 10



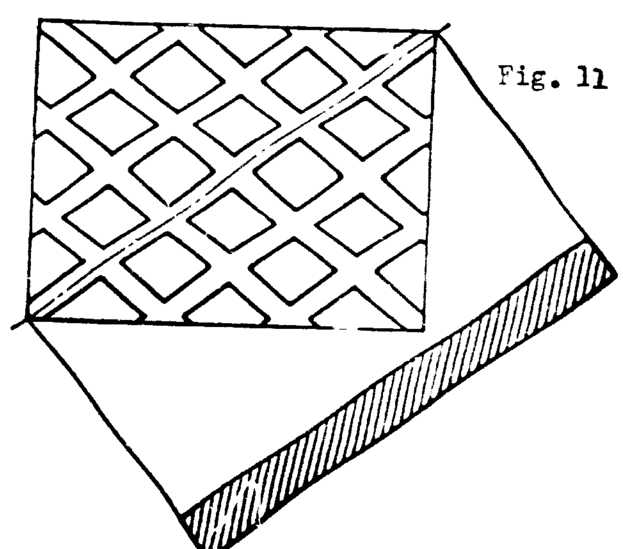


Fig. 11

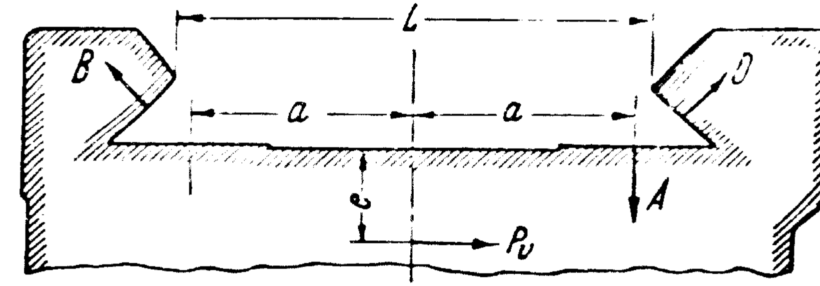


Fig. 12

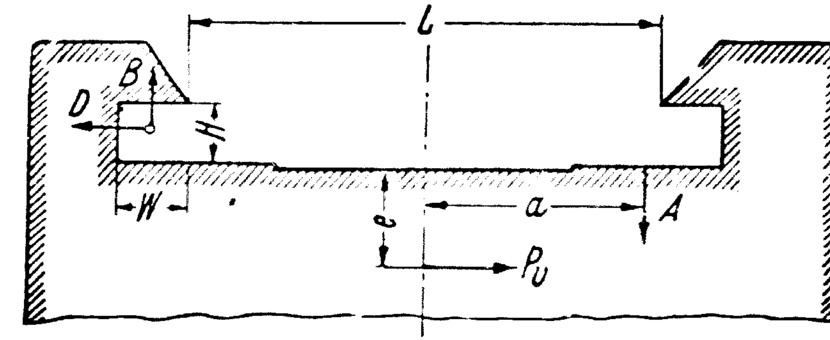


Fig. 13

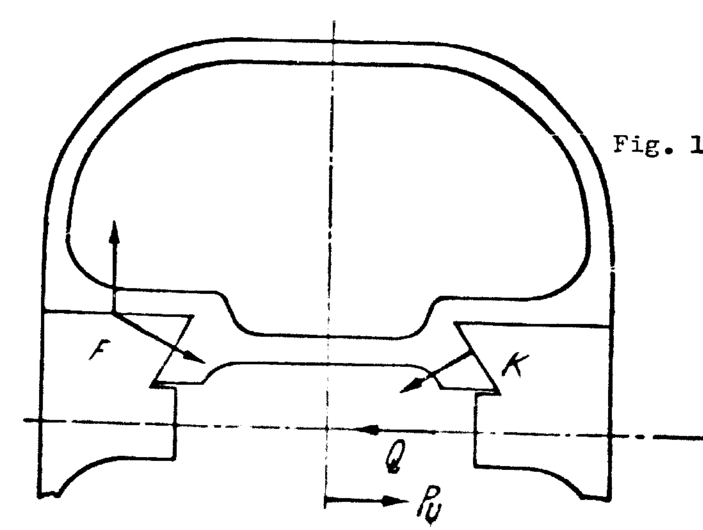


Fig. 14

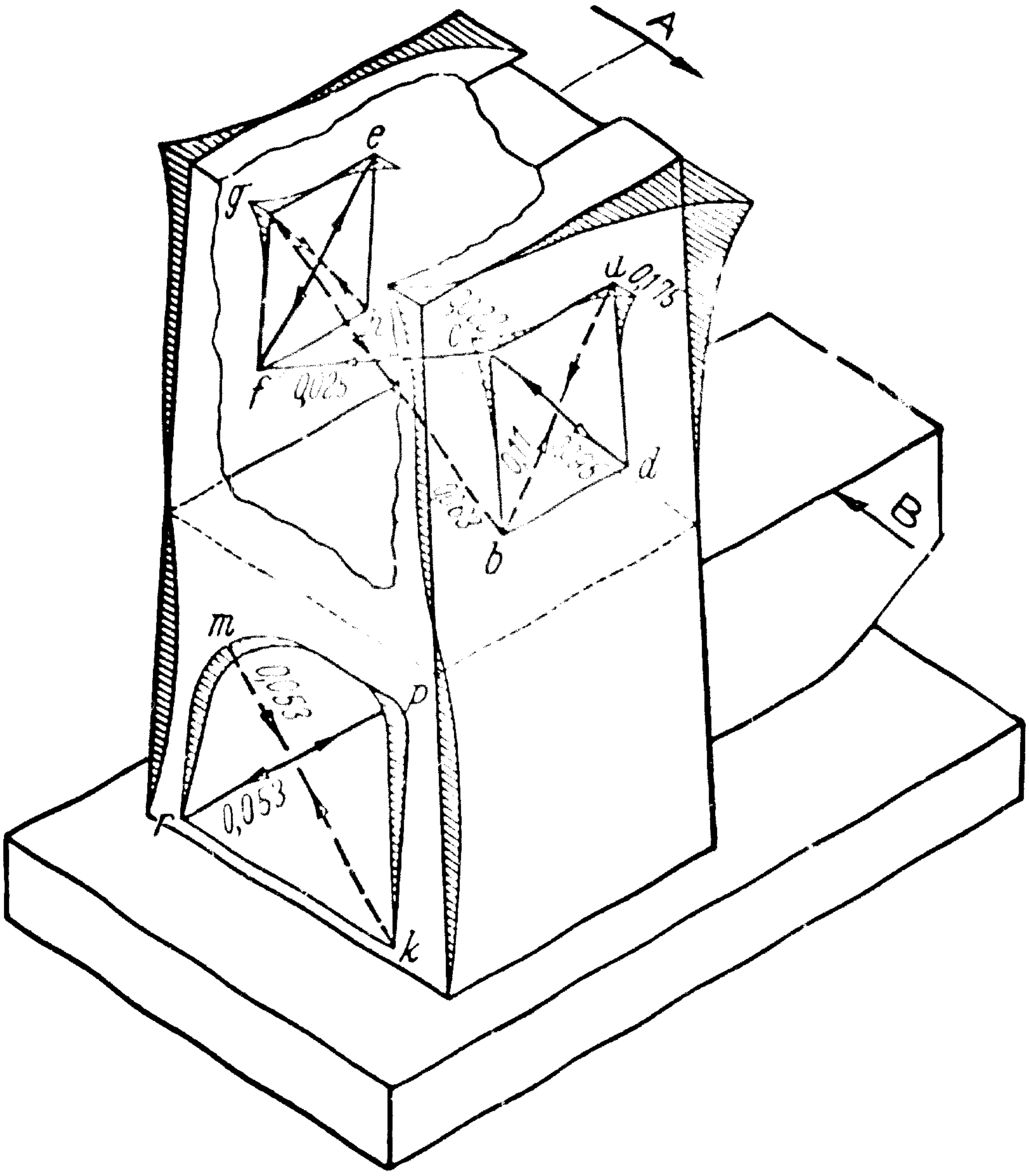


Fig. 15

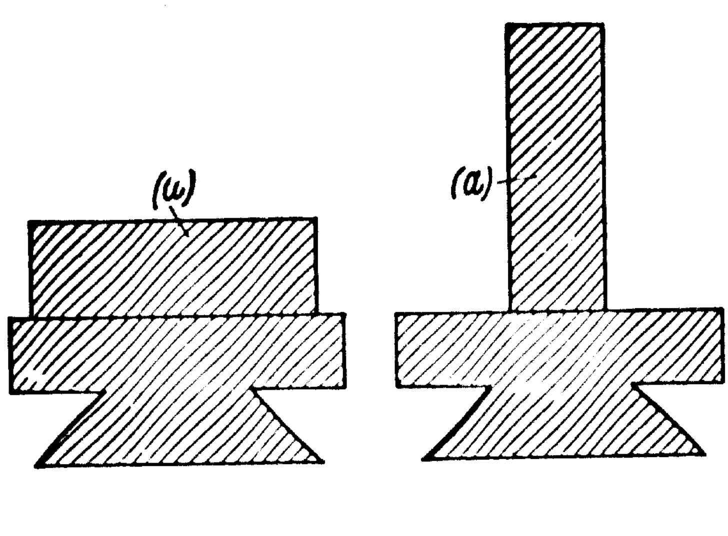
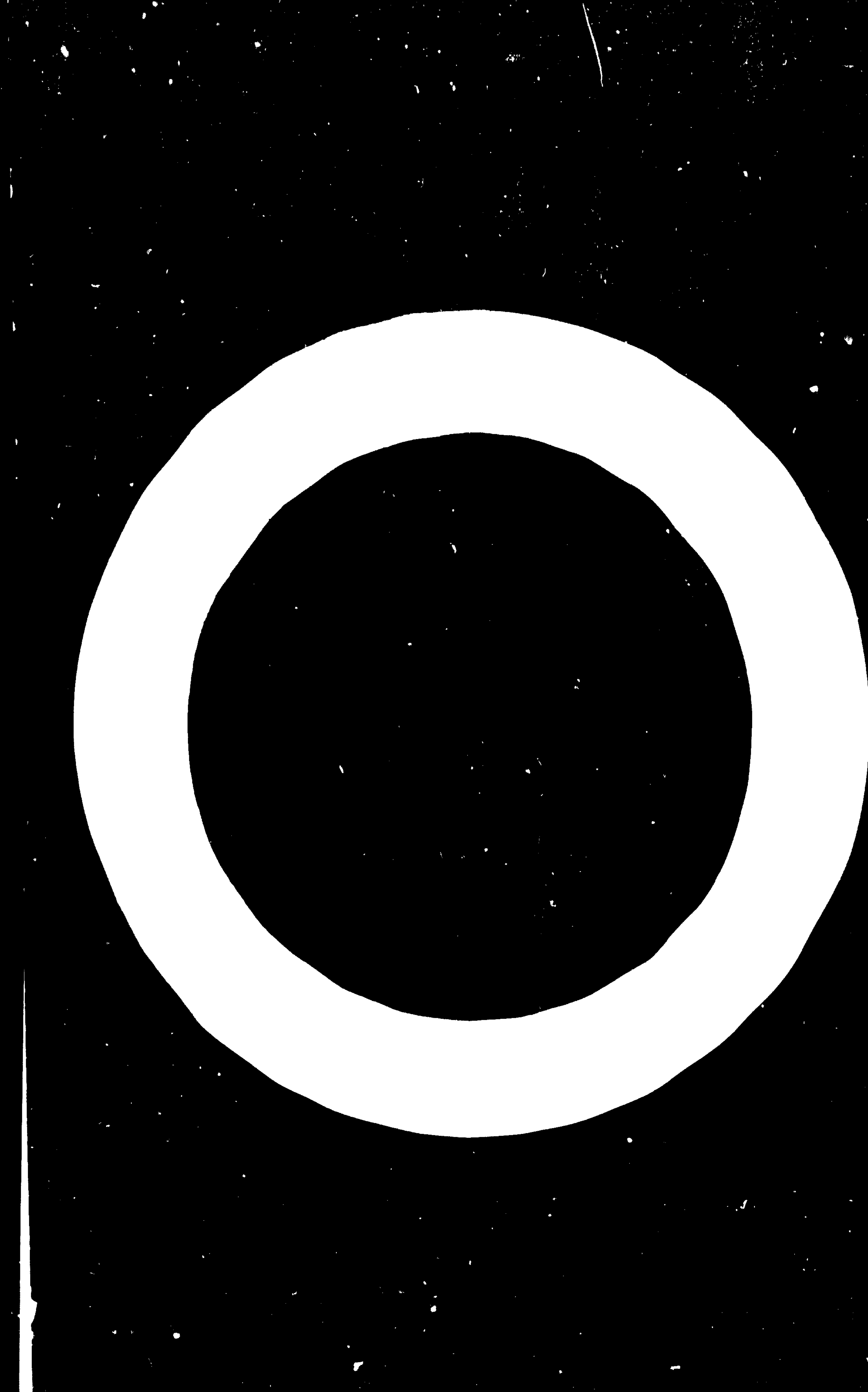


Fig. 16



It will be seen from table 3 that the reactions can become zero only in the case of design Fig. 12 when the feed force has a distance "c" indicated in the second row of table 3 (Page 31). In the case of design Fig. 13 the reactions do not become zero ,regardless of the distance of the feed force from the column face. Hence design Fig. 13 is to be given first choice. Friction forces have not been included in the formulae of table 3. If they are taken into consideration the conclusion will be more complex.

The preload with which an overarm is clamped to the machine column may affect the chance of vibration. Fig. 14 (Page 32 a) illustrates the cross section of a boxlike overarm. P_V is the feed force and Q the force with which the overarm is clamped. If "Q" is larger than top value of the vibratory force, friction damping is absent and vibration can be reduced by opening the claming screw (exerting force Q) . If the clamping force Q equals the mean value of the vibratory force, friction damping is usually indicated and hence the clamping force is satisfactory. On the other hand, when the clamping force is less than the lowest value of the vibration force, the clamping screw is subjected to periodic extension and contraction and thus not able to prevent vibration. Hence tightening of the screw is indicated. A device for self-adjustment of the clamping screw is therefore desirable.

Is it better to design the overarm with a large vertical or horizontal moment of inertia? To answer this question two overarms were built with the same mass but different moments of inertia (Fig 16 Page 32 b). The mass "a" was in one case horizontally in the other vertically arranged. The results indicated that for shallow cuts the right sketch of Fig.16 is preferable, for deep cuts the left hand design .

In order todetermine design data for the twist angle of lathe beds as affected by the base, model tests and full design tests were run. Fig 17 (Page 34a) is an illustration of the test stand which could be built at low cost.

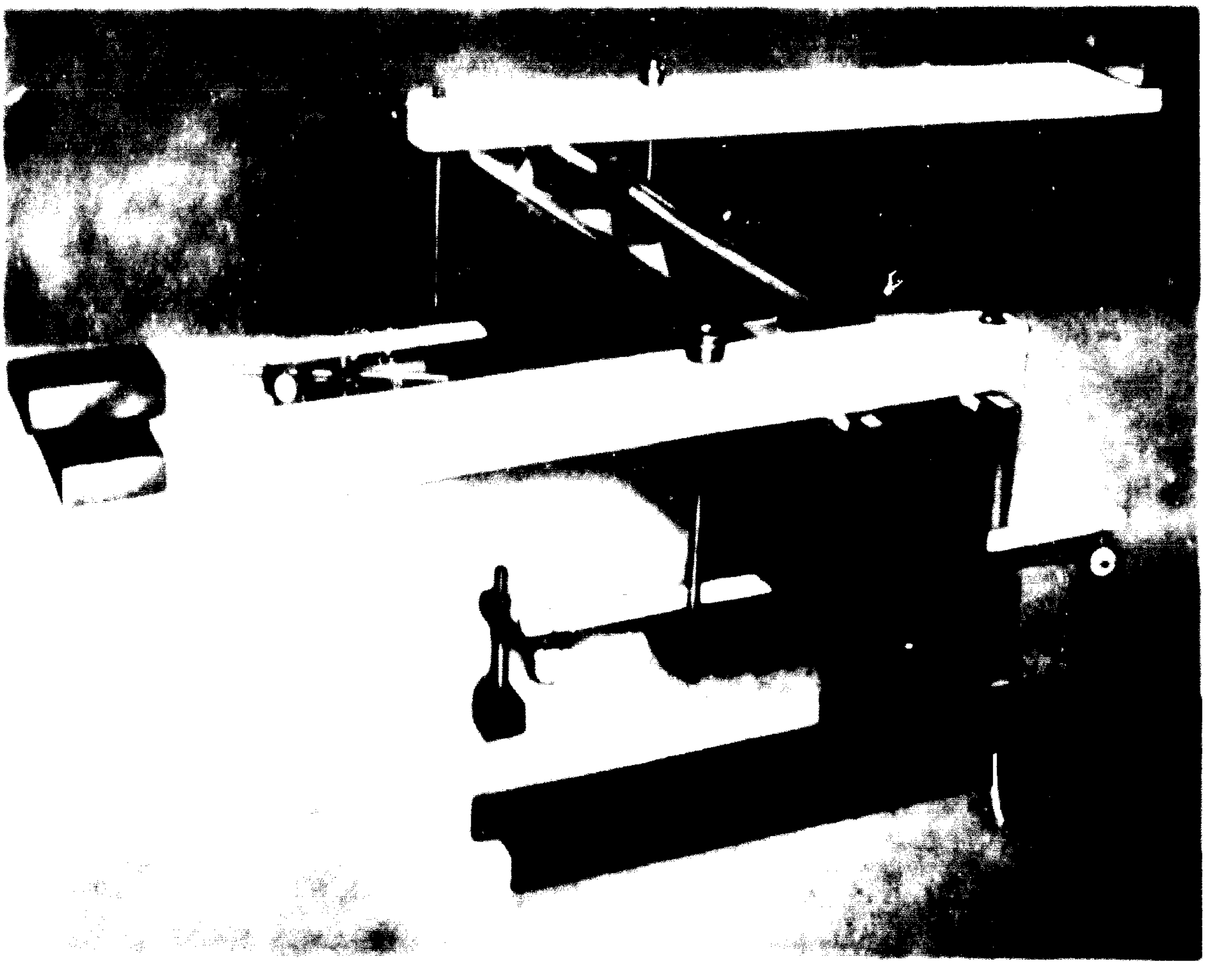
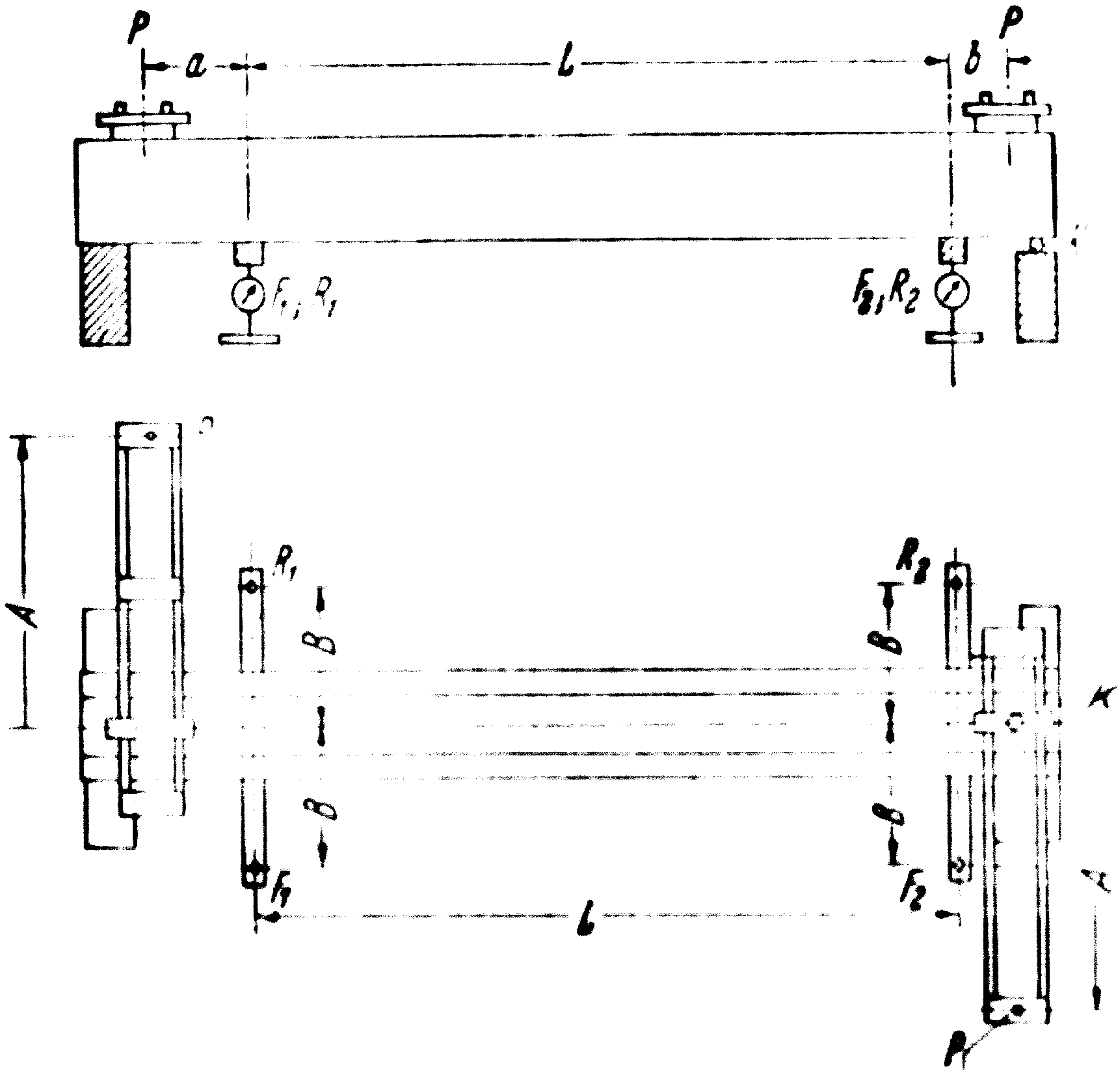


Fig. 17 Test stand for determining design data
(Twist of lathe beds)


P
a
l
b
P
F_1; R_1
F_2, R_2
A
R_1
B
B
F_1
l
R_2
B
B
K
F_2
A
P

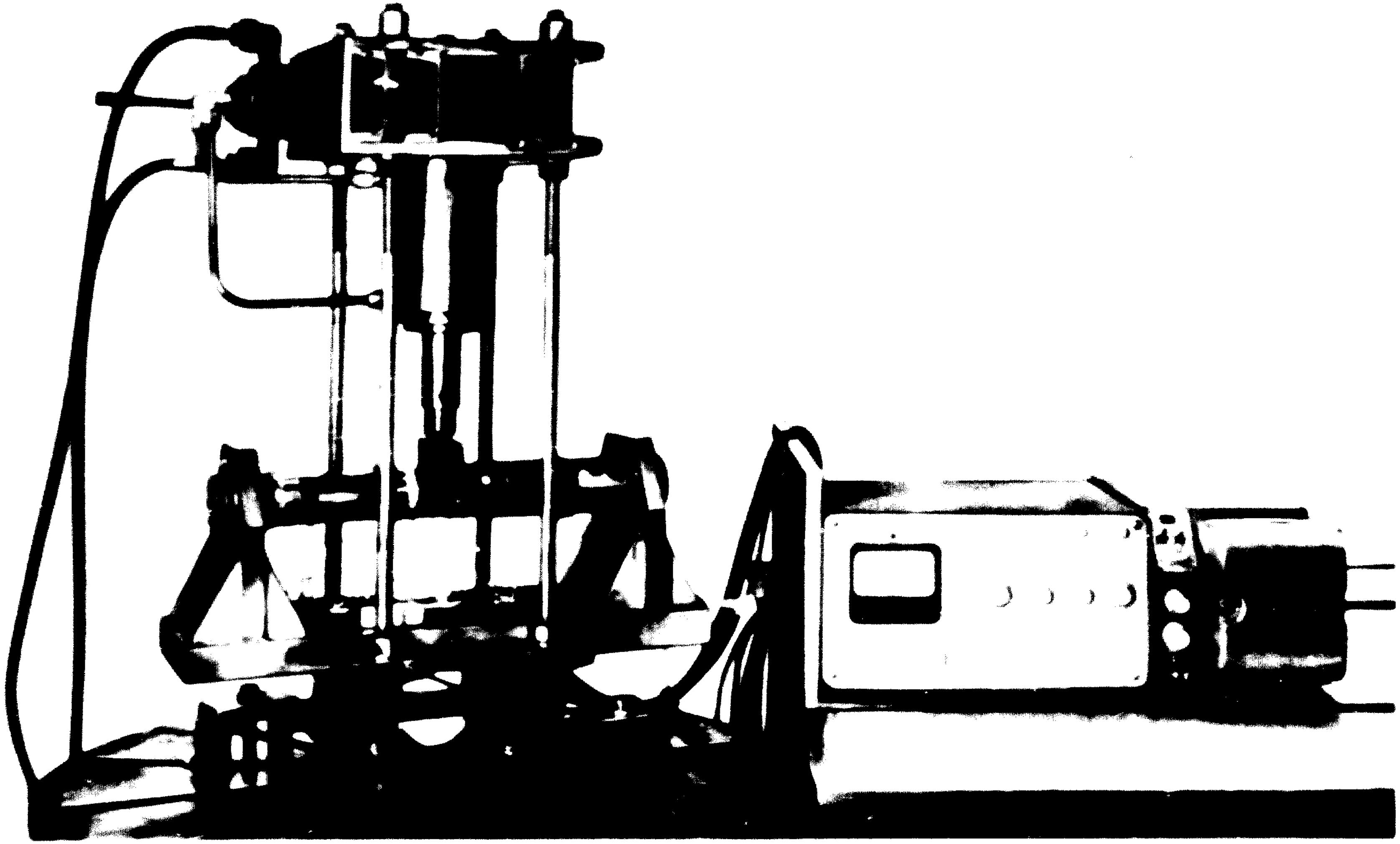
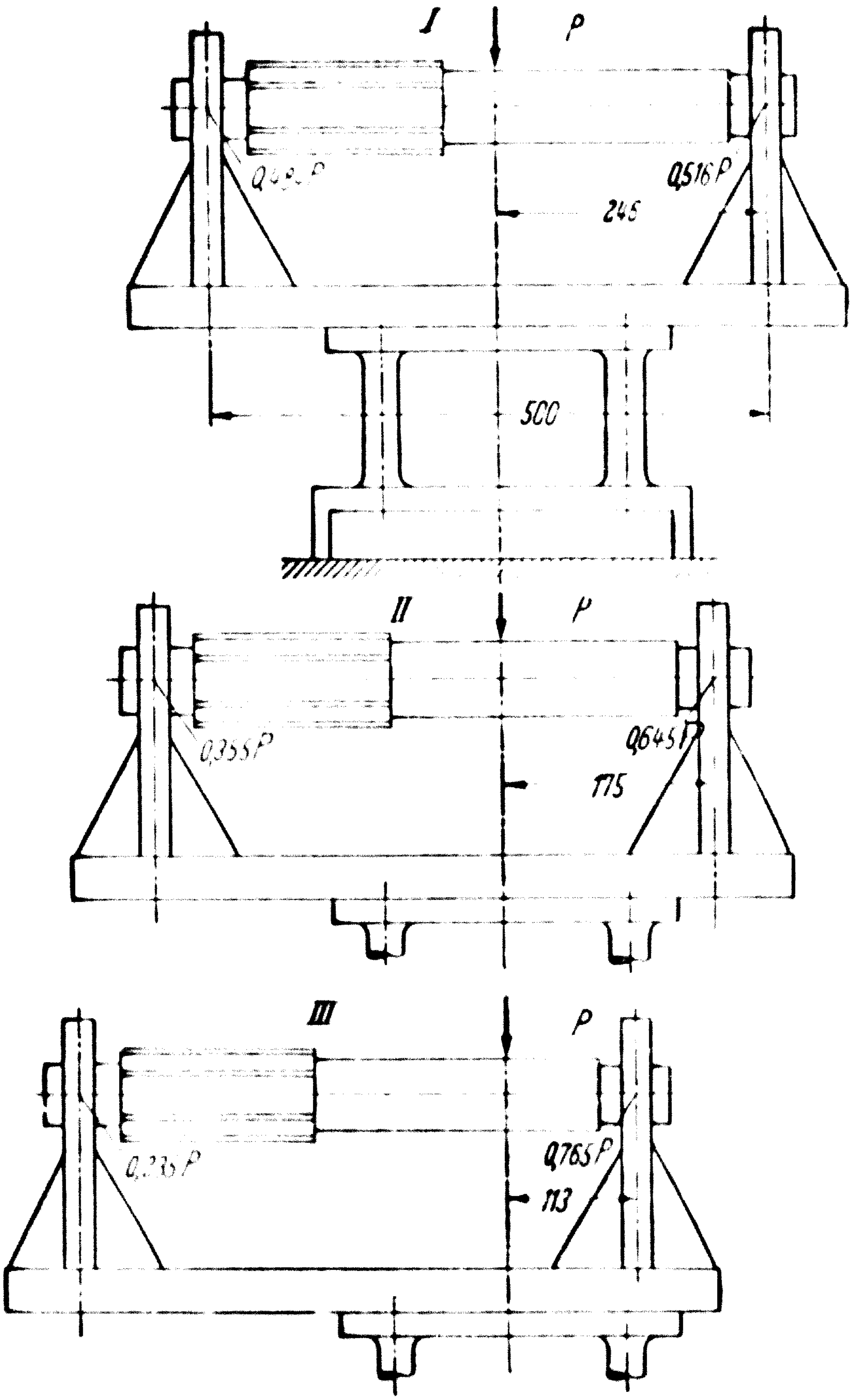


Fig. [illegible] [illegible]vice for determining [illegible] [illegible] [illegible]



I
P
0,516 P
245
500
II
P
0,355 P
0,645 P
175
III
P
0,765 P
113

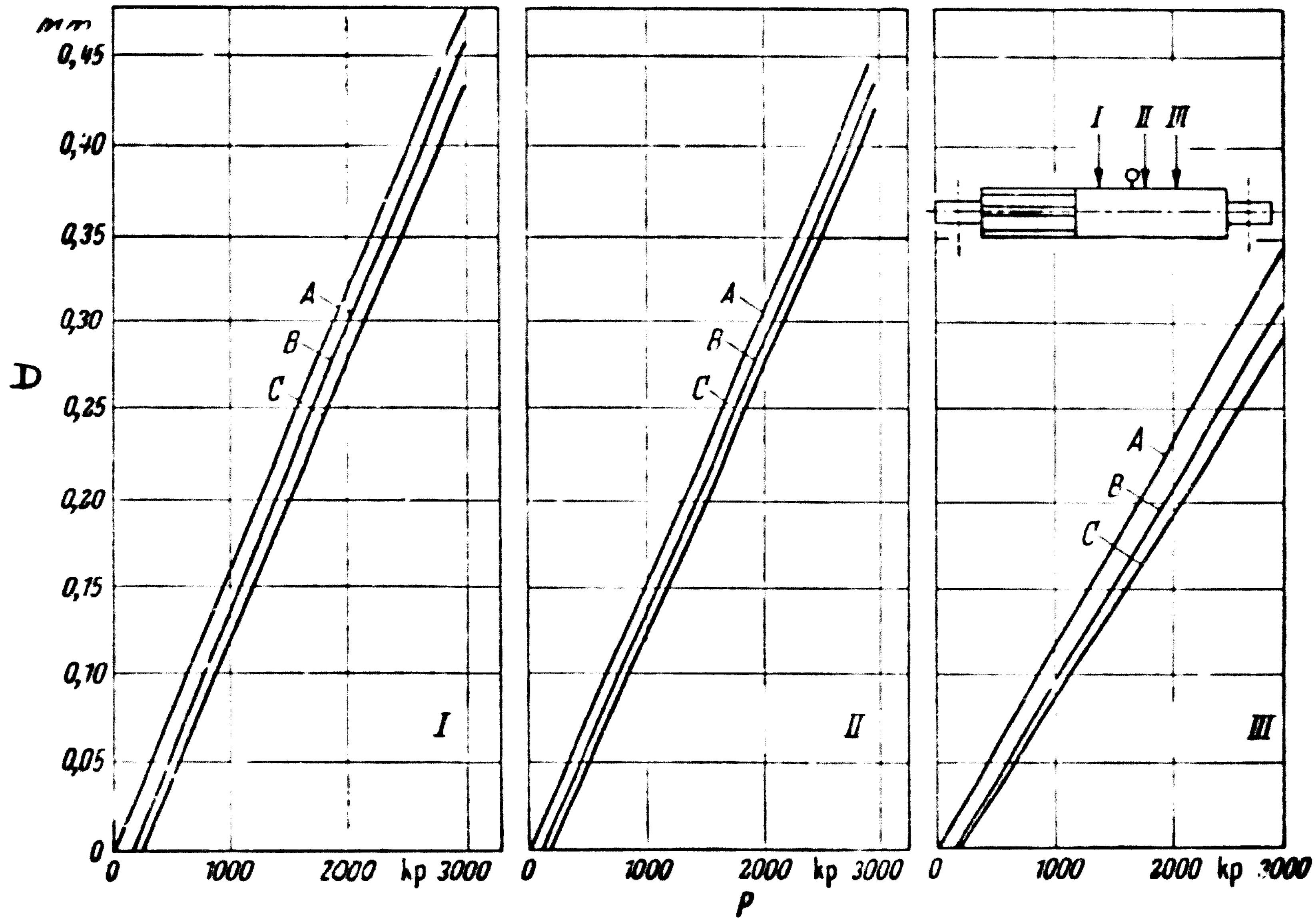

mm
D
0,45
0,40
0,35
0,30
0,25
0,20
0,15
0,10
0,05
0
0
1000
2000
kp
3000
P
A
B
C
I
II
III

Fig.21

The deformations were measured with dial indicators of high accuracy and the loads applied by placing calibrated weights on the two arms. The investigation was carried out with the bed only and with assembled bed and base. With the data indicated on Fig.18 (Page 34 b) the following formula was used for computing the deformation in terms of angle of twist:

$$\Theta = \frac{57.3\ (F_1 + R_1) - (F_2 + R_2)}{2.B.L.\ P\ .\ A} \qquad (4$$

The results indicated that the angle of twist is reduced when the bed is designed with a solid base by 83.5%.

<u>Design data in handbooks.</u>

In sone branches of Engineering it is often dificult to determine what the endconditions in practice are which are assumed in handbooks for the deflection and stresses generated in transmission shafts. In other words, are the shafts to be taken as "clamped", "supported" or "guided " etc?

Tests were therefore run to supply design data for the engineering department. Fig. 19 (Page 34 c)shows the hydraulic device for loading the spline shafts which were investigated for the stresses by means of strain gages. The same set up was then used for measuring the corresponding deflections. The shafts were supported in ball bearings, in Timken bearings, in plain bearings etc. and the data determined. The load could be applied at different points of the shafts by shifting the supporting frame sidewise (Fig. 20 Page 34 d) Thus three different load conditions could be evaluated, with different reactions at the bearings.

The results are shown on Fig 21 (Page 34 e) where the load F is plotted on the X- axis and the deflection D on the Y- axis. It will be seen that the theoretical handbook values (Lines A ,Fig 21) indicate larger deflections than the actually measured data, (Lines C, Fig.21) which take the preload as occurring in an assembled bearing into consideration. Lines B represent a loose bearing adjustment. The shafts are slightly bent upward by the preload of the bearings ,that is in opposite direction to the load. Vibration,due to change in the natural frequency of the shafts,is also affected by the bearing adjustment . It is thus advisable to be cau - tious in the application of handbook data which are valid for other fields of engineering where different bearing conditions exist.

Computer - aided design

The latest development in engineering product design is the use of computers . They are slowly but consistently entering the field of design after their great success in production ,cost accounting etc.
The design engineer formulates input data,has it programmed (or does it himself if trained in the art) and the computer delivers a range of results. As an example,programs for internal stresses in parts and equipment can be set up and the answers obtained from a computer. Among the advantages of the computer -in contrast to the conventional calculating machine - is the fact that the results can be saved and reused at a later date without writing down every item , even those that could not be applied the first time.
Rolling up and down a window in an automobile may appear as a simple activity of operating an equipment. The design of the mechanism ,however, involves 8000 linkage combinations (Ref 2). Fig. 22 (Page 37) shows the linkage for moving the window up and down. Less than 500 linkages would satisfy all design requirements and of these the computer would select the most desirable combination within the space limitations of the door size, and numerous other parameters. Equations for the optimum design are the basis of the computation.
The path of the motion of an automobile window is an involute curve followed by the front (F_1 ....F_4,Fig 23, Page 37) and by the rear($G.1$–$G.4$));the curves

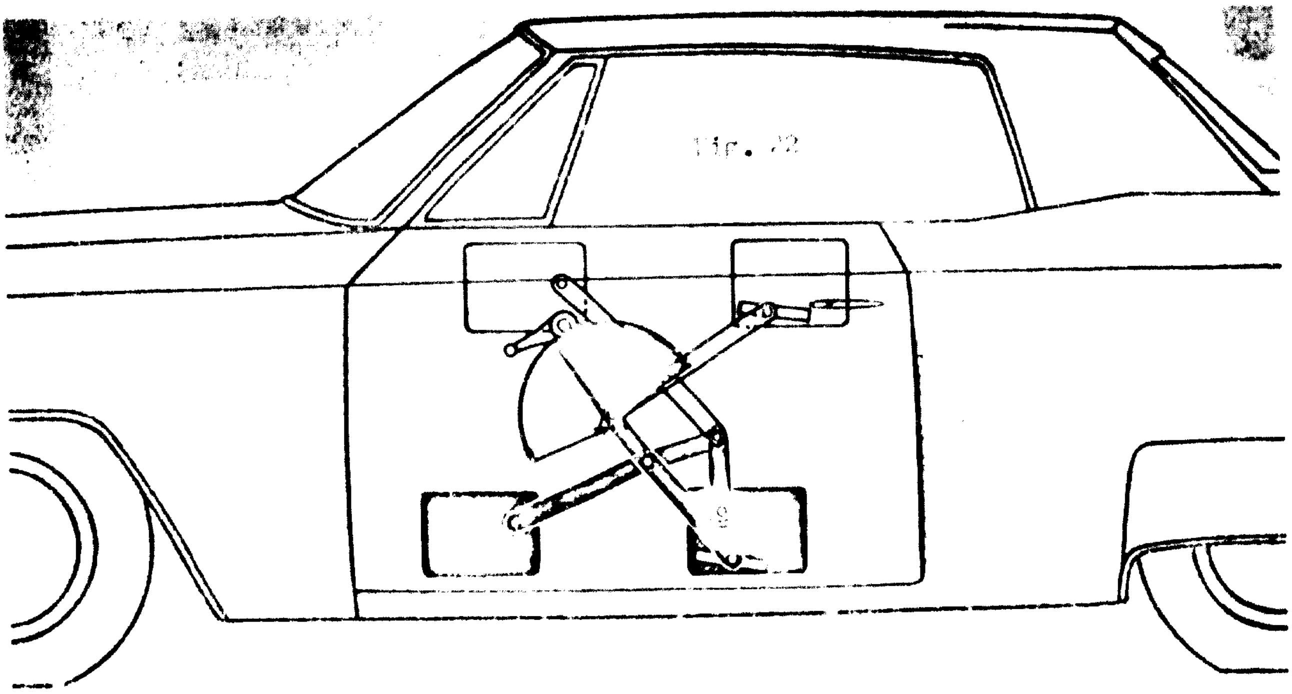
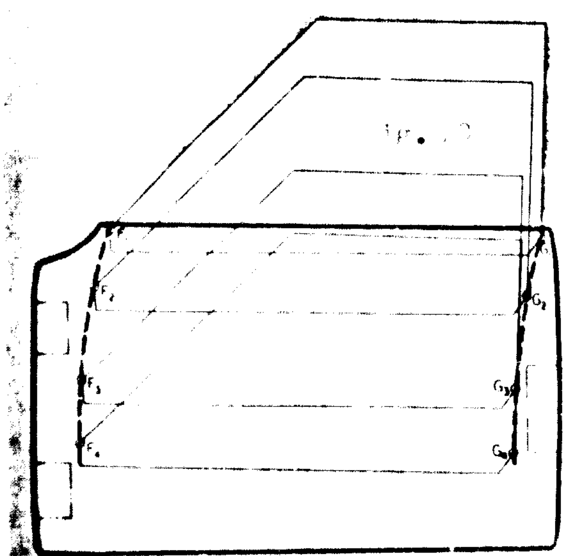


Fig. 22


F2
F3
F4
G2
G3
G4

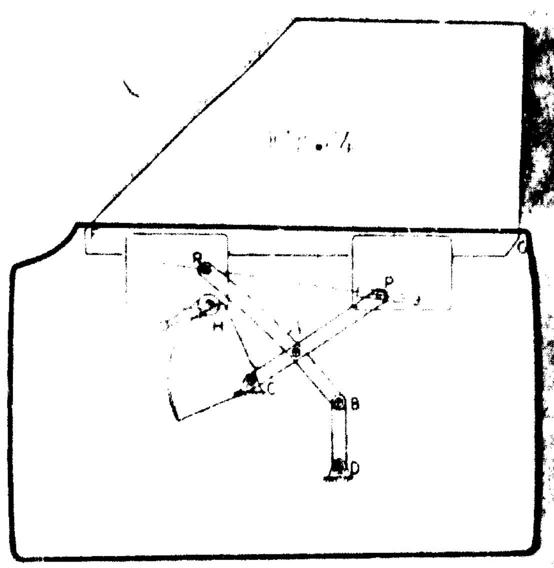


Fig. 24
R
H
P
C
B
D

are, however, not necessarily identical for best rolling up and down the window.

The cross arm mechanism (Fig 24, Page 37) provides the required window support and geometry of motion .It consists of the driver arm CAP and the equalizer link RAB. The driver arm controls the vertical motion, the link the horizontal motion. Pivot R is attached to the front holder while pivot P can move in a slot . The radius of the driver arm depends upon the distance of the line R - P in up position of the window from fixed point C ,upon the distance of line R - P in down position from point C ,on the angle of driver rotation and on an angle from up to down position of line R - P.
An equation for these relationships is used in the computation in conjunction with other equations such as the torque and others.
The computer delivers lists for the lengths of the link, for the pivot point location, for window-up and for window-down , lists of driver arm torque etc. within 45 seconds for most problems.

Computers are also being used for determining various designs of tractors and particularly for finding the physical reaction of the operator to different jerks, velocities, acceleration etc. in an attempt to lessen fatigue and provide a comfort zone. (Ref 3) . In this case analog computers are used for simulating the conditions. The system is reduced to its mechanical equivalent, that is to masses, springs etc. so that differential equations can be written and a wiring diagram be prepared. The voltage can be measured at any desired point and hence the analog quantity determined.
In combination with the computer it is possible to design a mechanical device for testing a tractor before it is built. Fig. 25 (Page 39) shows a platform with cylinders .If they are in phase the motion is pure bounce, if out of phase it is pitch. The oil flow is regulated by valves which can be controlled by electrical signals which may come from a tape record or an analog computer.

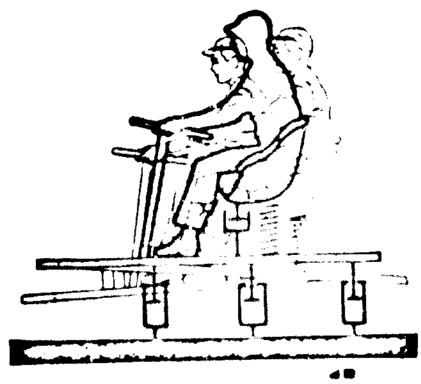
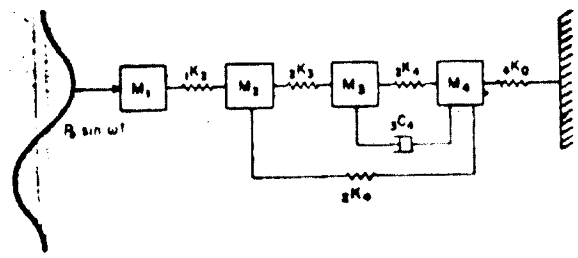


Fig. 25




```
5 SPRING CONSTANTS
1 K 2    0.60000E [illegible]
2 K 3    0.38860E [illegible]
2 K 4    0.38860E [illegible]
3 K 4    0.3860 E 09
4 K 0    0.50000E 08
1 DAMPING CONSTANTS
3 C 4    0.10000E 04
4 MASS CONSTANTS               FORCING FUNCTIONS
1 M 0    0.40000E 02           0.10000E 01        0.
2 M 0    0.46530E [illegible]  0.                 0.
3 M 0    0.46530E 01           0.                 0.
4 M 0    0.17200E 01           0.                 0.
1 W 2    OMEGA (CYCLES/SEC) =
0.10000E 03 TO   0.30000E 03 BY     0.10000E 03 INCREMENTS

OMEGA =          628.31853   RADIANS =      100.00000  CYCLES
   MAGNITUDE       ( 4- 0) =      0.33013E-08
   REAL PART       ( 4- 0) =      0.33009E-08
   IMAG PART       ( 4- 0) =     -0.91336E-08
 POLAR ANGLE       ( 4- 0) =      0.62876E 01
   MAGNITUDE       ( 4- 3) =      0.19013E-06
OMEGA =         1256.63700   RADIANS =      200.00000  CYCLES
   MAGNITUDE       ( 4- 0) =      0.90923E-08
   REAL PART       ( 4- 0) =     -0.90923E-08
   IMAG PART       ( 4- 0) =      0.24146E-10
 POLAR ANGLE       ( 4- 0) =      0.31442E 01
   MAGNITUDE       ( 4- 3) =      0.45797E-08
OMEGA =         1884.95559   RADIANS =      300.00000  CYCLES
   MAGNITUDE       ( 4- 0) =      3.48434E-09
   REAL PART       ( 4- 0) =     -3.48434E-09
   IMAG PART       ( 4- 0) =     -9.48833E-11
 POLAR ANGLE       ( 4- 0) =      0.31430E 01
   MAGNITUDE       ( 4- 3) =      0.29468E-08
```

Component design with computer aid.

Computers can be used to advantage in the design of components such as springs, gears, cams, belts, shafts and others. Usually a list is first prepared compiled on the basis of frequency with which the various components appear in the design and with regard to the difficulties involved in computations, thus freeing the designer from repetitious calculations. It is often not practical to try to take all problems into account that might come up, but include only problems which can reasonably be expected to be of aid to the designer.

The basic equations must be supplied by the designer as may be explained by an example for the design of gears. (Ref. 4). It is necessary to specify the need of the gear to operate with an existing gear, to design a pair of gears to operate at a given center distance or a center distance that is only approximately determined. The designer must determine the charakteristics of the gear material, the surface quality, the pressure angle, the velocities etc. He can limit the problem to exclude say the width of the teeth in order not to restrict the parameter.

Table 4 (Page 41) is an example for computerized gear design. The given data are listed at the top of Table 4, and include the quality class, the pressure angle (20°) while the face width is excluded by numeral " 0 ". The approximate center distance is given as 1.875", the input RPM is 1500, the output RPM 300. The input horsepower is not specified, while the input torque is given as 0.75 ft-lb. Other data given include: allowable pinion stress, gear stress and the moduli of elasticity for pinion and gear.

The computed design data for the pinion are listed in the second portion of Table 4 indicating that the number of teeth of the pinion must be 20, the diametral pitch 32, the max. circular thickness 0.04759", the outside gear diameter 0.6835", the tolerance + 0 /- 0.00625. The gear data are collected in

1. 2. 72

2 OF 2

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We regret that some of the pages in the microfiche copy of this report may not be up to the proper legibility standards, even though the best possible copy was used for preparing the master fiche

DATA GIVEN FOR REQUIRED GEAR

QUALITY CLASS	*	6.00000
PRESSURE ANGLE-DEGREES	*	20.00000
FACE WIDTH OF TEETH-INCHES	*	0.
APPROXIMATE CENTER DISTANCE-INCHES	*	1.87500
INPUT REVOLUTION PER MINUTE	*	1500.00000
OUTPUT REVOLUTION PER MINUTE	*	300.00000
INPUT POWER-HP	*	0.
INPUT TORQUE-FT-LB	*	0.75000
MAX. ALLOWABLE DESIGN STRESS FOR PINION-PSI	*	30000.00000
MAX. ALLOWABLE DESIGN STRESS FOR GEAR-PSI	*	30000.00000
MODULUS OF ELASTICITY-PINION-1000PSI	*	29000.00000
MODULUS OF ELASTICITY-GEAR-1000PSI	*	29000.00000

Table 4

COMPUTED DESIGN DATA-PINION

QUALITY CLASS-COMERCIAL-2		
NUMBER OF TEETH	*	20.00000
DIAMETRAL PITCH	*	32.00000
PRESSURE ANGLE-DEGREES	*	20.00000
STANDARD PITCH DIAMETER-INCHES	*	0.62500
TOOTH FORM-AM.STD.FULL DEPTH INVOLUTE		
MAX.CIR.THICKNESS OF STD. PITCH CIRCLE-INCHES	*	0.04759
TESTING RADIUS-INCHES	*	0.31050
TOLERANCE OF TESTING RADIUS-INCHES	+.000.-	0.00400
MAX.COMPOSITE RADIAL VARIATION-INCHES	*	0.00400
MAX.TOOTH TO TOOTH VARIATION-INCHES	*	0.00150
OUTSIDE DIAMETER OF GEAR-INCHES	*	0.68350
TOLERANCE ON OUTSIDE DIAMETER-INCHES	+.000.-	0.00625

COMPUTED DESIGN DATA-GEAR

QUALITY CLASS-COMERCIAL-2		
NUMBER OF TEETH	*	[illegible]
DIAMETRAL PITCH	*	[illegible]
PRESSURE ANGLE	*	20.00000
STANDARD PITCH DIAMETER-INCHES	*	[illegible].12500
TOOTH FORM		
MAX.CIR.THICKNESS [illegible]	*	0.04759
TESTING RADIUS [illegible]	*	1.56050
TOLERANCE [illegible]	+.000.-	0.00400
MAX.COMPOSITE [illegible]	*	[illegible].00400
MAX.TOOTH [illegible]	*	[illegible]
OUTSIDE DIAMETER [illegible]	*	[illegible].16350
TOLERANCE [illegible]	+.000.-	[illegible].00625
CLEARANCE [illegible]	*	[illegible]
FACE WIDTH [illegible]	*	[illegible].25000
CIRCULAR [illegible]	*	[illegible]
STANDARD [illegible]	*	1.87500
TOLERANCE [illegible]	[illegible]	[illegible].00200
MAXIMUM [illegible]	*	[illegible].01070
MINIMUM [illegible]	*	[illegible].00150
NUMBER OF [illegible]	*	[illegible]
GEAR RATIO		[illegible]
CALCULATED [illegible]	*	[illegible]
PITCH [illegible]	*	[illegible]
MAX. [illegible]	*	[illegible]
MAX. [illegible]	*	[illegible]
AVERAGE [illegible]	*	[illegible]
AVERAGE [illegible]	*	[illegible]
[illegible]	*	[illegible]
[illegible]	*	[illegible]
[illegible]	*	[illegible]
[illegible]	*	[illegible]

END OF [illegible]

Example of input and output from a sample problem in spur-gear design [illegible]

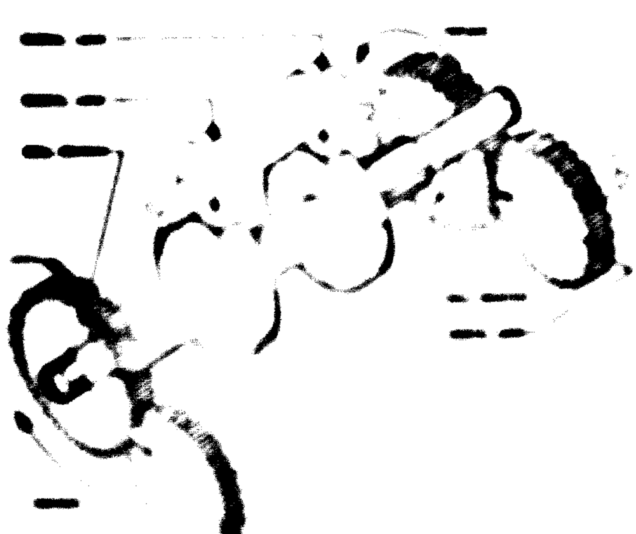


Fig. 26

[illegible]

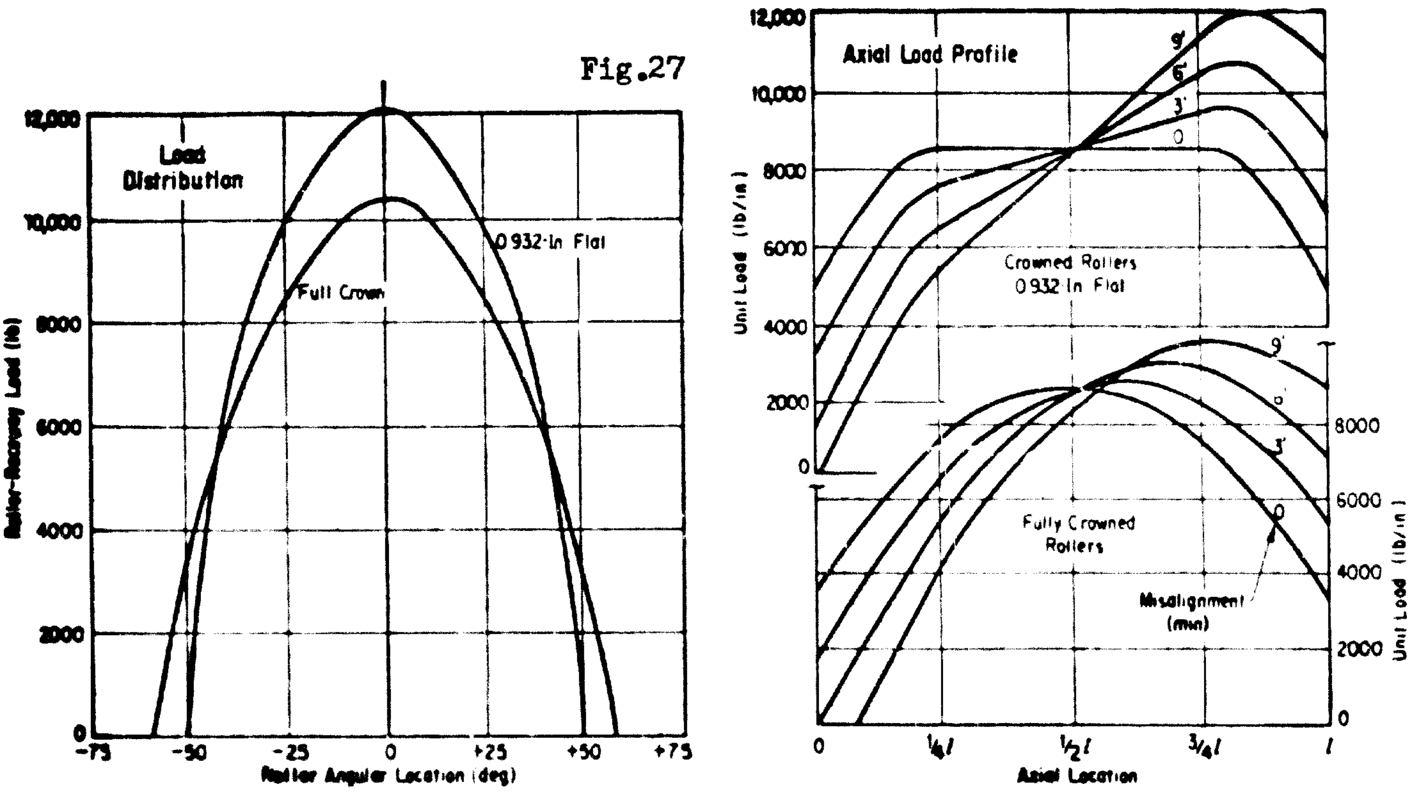
the third portion of Table 4 (Page 41). The pitch diameter of the gear must be 3.125" ,its outside diameter 3. 1835" .The clearance is indicated as 0.00825" and the width of the teeth (which had not been specified by the designer ,see top portion of Table 4) is given by the computer as 0.25". Other data for the design of the gear include the tolerance of the center distance , the number of teeth in contact,the ratio of transmission, the pitch line velocity ,the max. permissible torque,the sliding velocities, the efficiency and the various stresses.

The data obtained from the computer may suggest to alter the design and to recompute the various data,which is done in a very short time and thus aiding the designer tremendously,reducing the cost and expedite the completion of the design.

Computers for a three dimensional problem-see the gear drive transmission of Fig 26 (page 41)- can also be programmed for computer design. Combination of several design jobs is possible ; to facilitate this the component design programs are maintained on magnetic tape and records are kept ,enabling the designer to find a desired program.

In cases where a great number of gears are engaging in various ways the computer aided design is likewise of great help (Ref 5),even for companies that do not have computers in their own plant. In such cases use is made of renting computer time from a central service organization by cable or by sending the program information to the service organization. The computer can advise the designer of illogical input data ;it cannot determine the shaft location ,as an example, if other data such as the gear diameters are too large for mesh within the given tolerances.The computer stops working or a light appears as a signal.

Fig.27



The analysis of load distribution in bearings is complicated but has now also been programmed for computers. This makes the design considerably easier because the information can be used for predicting bearing life for alternate conditions.

The above diagrams (Fig. 27) have been plotted from computer determined data for roller bearings with 14 cylindrical rollers (Ref. 6) of 40 mm diameter and 40 mm length. The bearings have a pitch diameter of 205 mm, and have to carry a max load of 30 000 Lb. The misalignment must not exceed 9 min. and the clearance at operating temperature should be 0.004". The graphs show the results and may be used for finding the max. load per unit length, the load at the roller edges, the contact length of roller and race way etc. The effect of flats on the rollers on the unit load can likewise be read from the diagrams.

In engineering design the "Fortran" computer language is mostly used in the United States. The term "Fortran" is derived from "Formula Translation", it indicates that this "language" is particularly well adapted to solving formulas by computer. Arithmetic functions are expressed by a Fortran function consisting of a few letters, such as

square root = SQRTF (the "F" indicates function), exponential = EXPF; sine = SINF, nat.logarithm = LOGF etc.

Several methods are used in getting data and programs into the computer, namely magnetic tape, punched paper tape, cards, and typewriter. In the first case magnetic spots are produced on the tape representing the data. It is a high speed method and usually used in large scale computers. In engineering computers the paper tape is more common; it rolls from a supply roller to a collecting roller. Cards are also widely in use. A different card is needed for each instruction in the program. The typewriters look like customary designs, except that depressing a key transmits an electrical signal to the computer. The typewriter prints also out the results from the computer.

In the design of a component such as a steel beam, the deflection and the stress are usually needed by the designer. From the formulas

(stress) $s = 6\ PL/bh^2$ (5

(deflection) $d = 2sL^2/3\ Eh$ (6

the computer prints the answers in this way:

Stress	Deflection	Length	Width	Thickness	Force
1500.000	.000416	.50000	.05000	.02000	.10000
3000.000	.000833	.50000	.05000	.02000	.20000
4500.000	.001250	.50000	.05000	.02000	.30000

A further step in the direction of computerizing the design of engineering products is the development of drafting machines that are controlled by punched tape in a similar manner as numerically controlled machine tools. It is possible in this way to prepare drawings from formulas or data given as coordinates ,particularly in the case of complex contours.
Although computer aided design is still in the initial stage it is clear that it is going to play an increasing role in the near future. It will require more analytical training for the designer and may displace design engineers engaged in repetitive work. It will mean an "upgrading" of the designer in that he will be able to devote more time to creative and inventive engineering. The cost of programming is still often too high but will decrease in the years to come and thus benefits arising from computerizing will also become available to the engineering office.

Optimization

In cases where the computer yields a series of solutions of equal technical quality ,the cost factor will enter as a significant quantity in deciding the final selection of the various design possibilities. This process is known as "Optimization".
It can be obtained by trial and error methods,by modifying the successive designs, by experiments ,by mathematical means and computer. It can become rather involved when it is necessary to make use of matrices, non-linear equations etc (Ref. 7).
For the sake of simplicity an example shall shortly be discussed which is taken from the field of optimization of machining of metals as outlined by the author(Ref. 8) because the basic principles are the same as in the case of design. The problem is to decide whether a brazed or a throw away carbide tool should be used in the machining of a given metal . Both tools have the same tool life and cutting speed. Also the feeding time (or cost), rapid traverse cost and other factors are the same as will be seen from Table 5.

Lower cost will therefore be the criterion for the selection . A computer is used for rapidly determining the cost and compare the two possibilities for the tool. Table 5 (Page 47) indicates that the throw away carbide tool when used at a speed of 940 ft/min -even though the tool life is only 5 minutes - is to be preferred . The cost per piece amounts to $ 0.90 in this case as against $ 2.15 in the case of a brazed carbide tool used at the same speed of 940 ft/min . It will also be noted from Table 5 that the brazed carbide tool run at 600 ft/min with a tool life of 37 min would still be more expensive namely $ 1.25. A high speed steel tool at 5 min tool life would rise the cost to $ 5.40 . The resp. data have been circled on Table 5.

Kitchen utensils

The design of kitchen utensils which are typical consumer goods depends to a large extent on the manufacturing methods that are available or may be considers by the designer. This is facilitated by using the equipment of companies which rent out the resp. machinery or manufacture certain designs on a contract basis.

Several examples of kitchen utensils are illustrated on Fig. 26 (Page 48). They can be manufactured by a relatively new process known as floturning or hydro-spinning. It permits high production rates (at relatively low cost) of consumer goods that should not only be useful and practical but also satisfy the sense of beauty of the consumer. As an example, the four mixing bowls at the left side of Fig. 26 (Page 48) are made of stainless steel of 0.037" wall thickness. The designer, however, is not limited to have the thickness of the side walls of the same dimension as the original material or the flat bottom of the bowls. He can thin out the side walls and have a heavier rim around the open end, thus producing an aesthetic design. The same consideration applies to the design and manufacture of the other parts shown on Fig. 26, which include seamless hoppers, coffee percolators, drinking cups etc.

Table 5

TABLE 5

COST AND PRODUCTION RATE FOR TURNING

BRAZED CARBIDE TOOLS

DATA SET NO	WORK MATERIAL	HARD-NESS	TOOL MATL	CUT SPD F/M	FEED IN/REV	TOOL LIFE MIN	FEED COST $	RAPD TRAV $	LOAD UNLD $	SET UP $	TOOL CHNG $	TOOL DEPR $	TOOL SHPN $	RE BRAZ $	TIP COST $	GRIND WHEEL $	TOTAL COST $/PC	PROD RATE PC/HR
9	SAE 410 SS	202	C-7	940	0.0100	5	0.27	0.04	0.34	0.15	0.27	0.08	0.83	0.09	0.01	0.02	2.15	8.1
10	SAE 410 SS	202	C-7	760	0.0100	15	0.34	0.04	0.34	0.15	0.11	0.03	0.34	0.03	0.00	0.01	1.43	8.9
11	SAE 410 SS	202	C-7	640	0.0100	30	0.40	0.04	0.34	0.15	0.06	0.02	0.20	0.02	0.00	0.00	1.27	8.8
12	SAE 410 SS	202	C-7	600	0.0100	37	0.43	0.04	0.34	0.15	0.05	0.01	0.17	0.01	0.00	0.00	1.25	8.6

COST AND PRODUCTION RATE FOR TURNING

THROWAWAY CARBIDE TOOLS

DATA SET NO	WORK MATERIAL	HARD-NESS	TOOL MATL	CUT SPD F/M	FEED IN/REV	TOOL LIFE MIN	FEED COST $	RAPD TRAV $	LOAD UNLD $	SET UP $	INDX INST $	HLDR DEPR $	INSERT COST $	TOTAL COST $/PC	PROD RATE PC/HR
109	SAE 410 SS	202	C-7	940	0.0100	5	0.27	0.04	0.34	0.15	0.02	0.00	0.06	0.90	10.6
110	SAE 410 SS	202	C-7	760	0.0100	15	0.34	0.04	0.34	0.15	0.00	0.00	0.02	0.92	10.0
111	SAE 410 SS	202	C-7	640	0.0100	30	0.40	0.04	0.34	0.15	0.00	0.00	0.01	0.97	9.4
112	SAE 410 SS	202	C-7	600	0.0100	37	0.43	0.04	0.3[illegible]	0.15	0.00	0.00	0.01	0.99	9.1

COST AND PRODUCTION RATE FOR TURNING

SOLID HIGH SPEED TOOLS

DATA SET NO	WORK MATERIAL	HARD-NESS	TOOL MATL	CUT SPD F/M	FEED IN/REV	TOOL LIFE MIN	FEED COST $	RAPD TRAV $	LOAD UNLD $	SET UP $	TOOL CHNG $	TOOL DEPR $	TOOL SHPN $	GRIND WHEEL $	TOTAL COST $/PC	PROD RATE PC/HR
13	SAE 410 SS	202	T-1	220	0.0100	5	1.18	0.04	0.34	0.15	1.18	0.08	2.37	0.03	5.40	3.0
14	SAE 410 SS	202	T-1	180	0.0100	15	1.45	0.04	0.34	0.15	0.48	0.03	0.96	0.01	3.49	3.6
15	SAE 410 SS	202	T-1	158	0.0100	30	1.65	0.04	0.34	0.15	0.27	0.01	0.55	0.00	3.04	3.6

Fig. 28

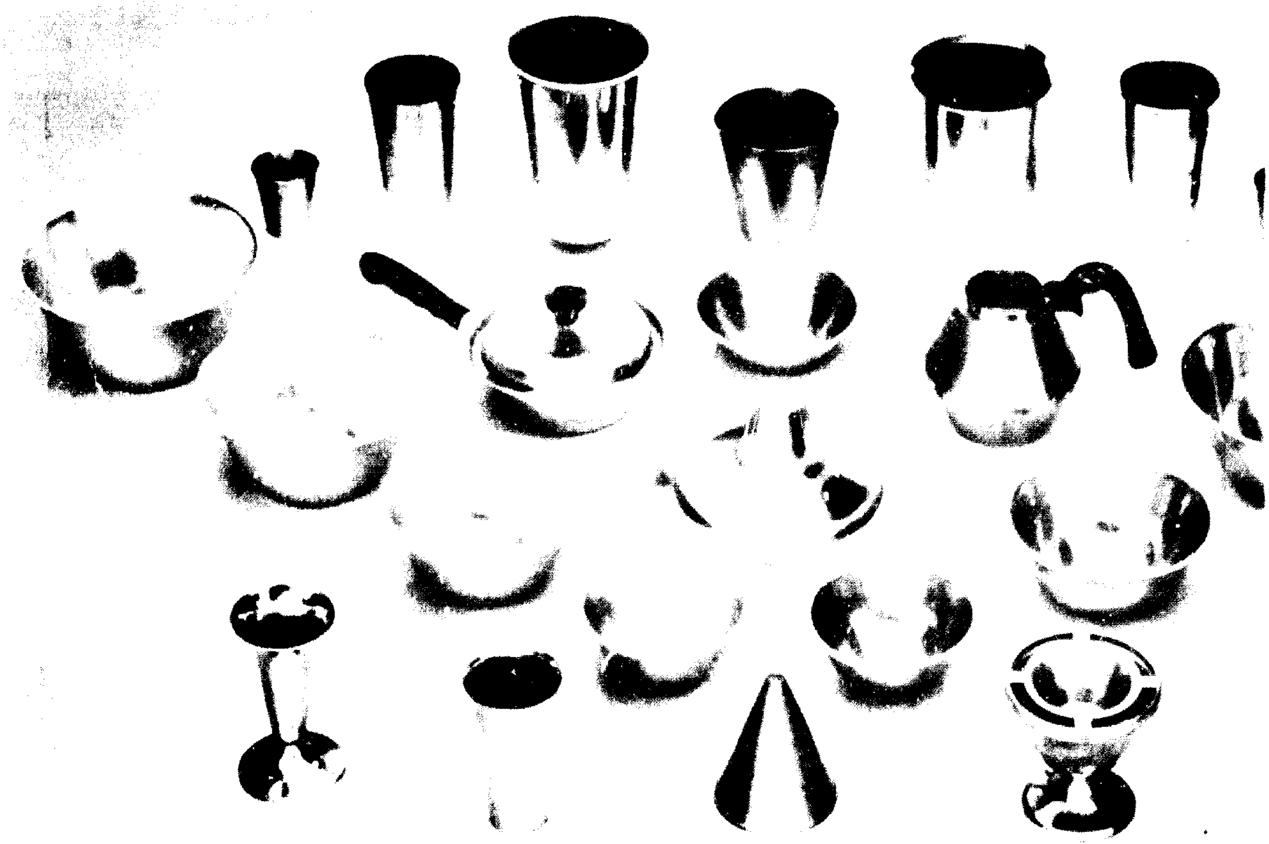


Fig.29

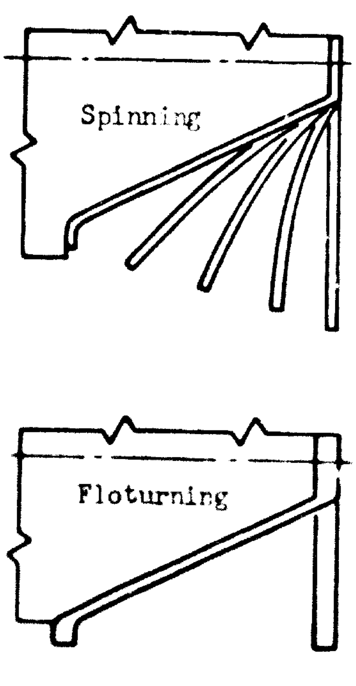
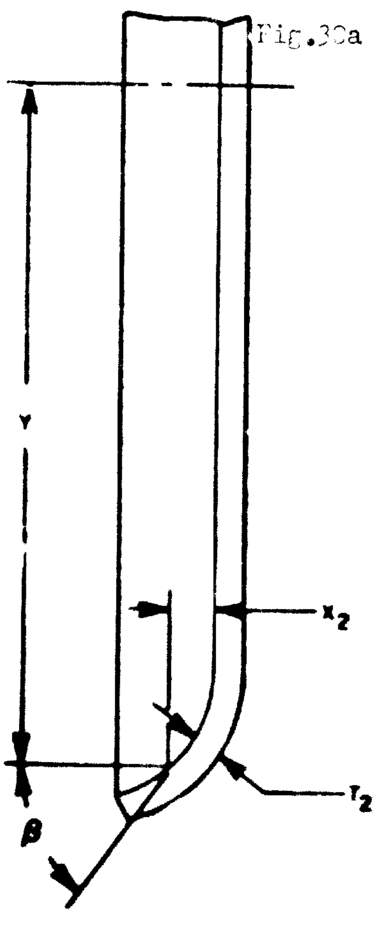
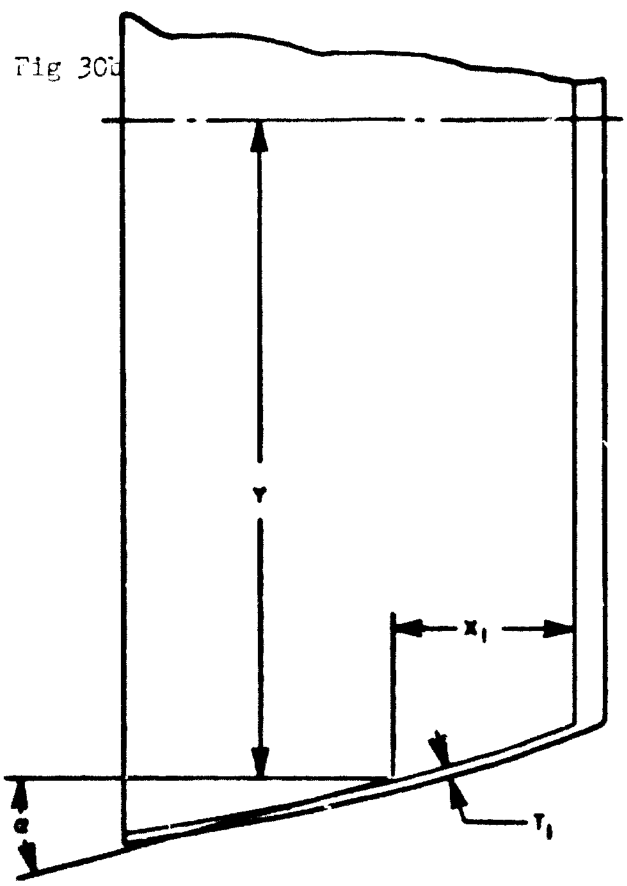


Fig.30a Fig 30b





Upon first consideration it might be thought that flo turning is very similar to conventional spinning. There are however considerable differences. Conventional spinning utilises a relatively thin piece of material and produces the shape of the finished part from the diameter of the starting blank, while the flo turn process (Ref. 9) does not change the diameter or shape of the original blank ,but produces a finished shape by working from the thickness of the blank producing a considerably thinner part. Fig 29, Page 48, shows a rough comparison between spininng and flo turing of a tapered part.

The author participated partly in the earlier development of the method which must be understood by the designer as is always necessary in the design of engineering products regardless whether they belong into the category of industrial machinery ,equipment or consumer goods. The designer must be familiar with the manufacturing processes;his designs might not be producible if he has no knowledge of the production method involved. On the other hand a new or improved manufacturing method opens new fields for the designer.

In the case of the mixing bowls (Fig. 28, Page 48)the design starts with the dimensioning of the drawn blank (Fig 30 a Page 48) in order to determine the proportions of the finished part (Fig 30b Page 48).Involved are the values for T_2,Y, β ,x_2 (Fig 30 a) and for T_1,Y, α ,x_1 . The relationship is expressed by trigonometric functions which may be computed in a stepwise fashion ,that is in small increments around the curvature of the blank.

Other design considerations

There are numerous other types of designs which can only shortly be touched upon here. As an example, the human body size must be taken into consideration in the design of equipments such as work places, office desks, controls etc.

Fig.51 (Page 51) shows some illustrations for the correlation of the human body size and the design of workplaces. If an equipment is located above an aisle (Ref 10) Fig. 51 a the vertical clearance for a tall man plus shoes and possibly a safety helmet is about 76 to 77 inches. With the height which can be reached by a short man of only 76 to 78", the vertical clearance range can be only about 1 to 2 inches.

The short operator must be used as the standard where it is necessary for the operator to see over an equipment rack (Fig 51 b , Page 51) Controls on vertical racks should not be placed more than 74 inches above the floor and 30 inches should be allowed behind the operator.

Similar design rules apply to foot operated equipment ,where the foot separation should be 6 inches ,the foot pedal should be large enough to support the foot comfortably.

In the design of controls the size ,shape location,direction of motion, path of motion,effect of temperature , operator's position ,clothing restrictions are among the factors to be taken into consideration.

All new design possibilities can often not be anticipated .In such cases it is adviseable to create a socalled "mockup" which is similar to a model ,as discussed above for industrial machinery, except that it is consists of card board or similar simple material,because forces do usually not enter here.

Fig. 31

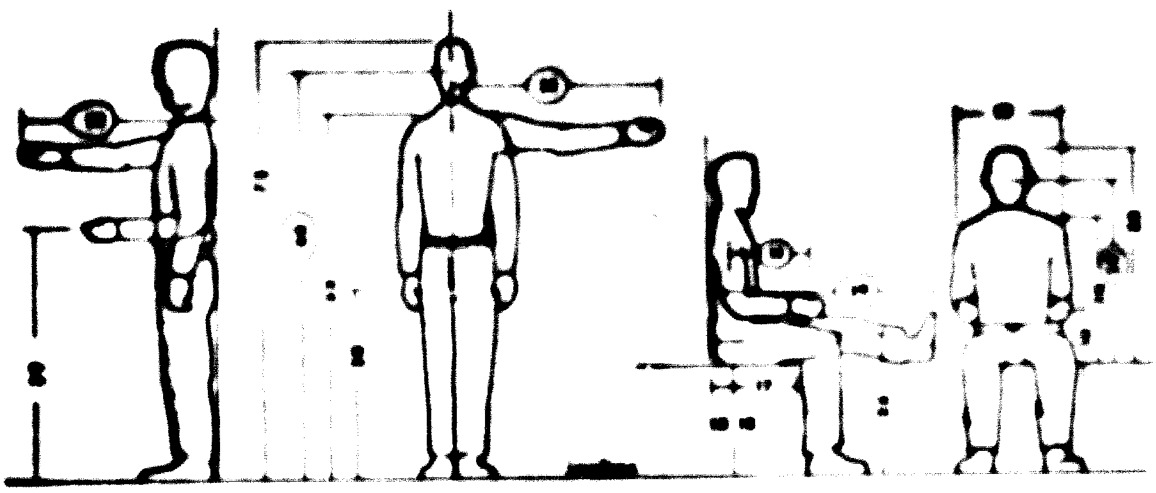
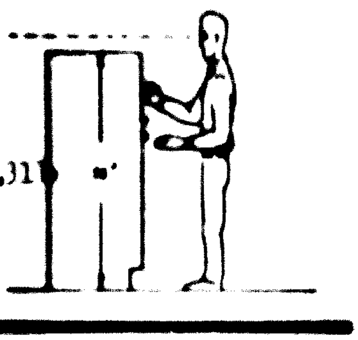
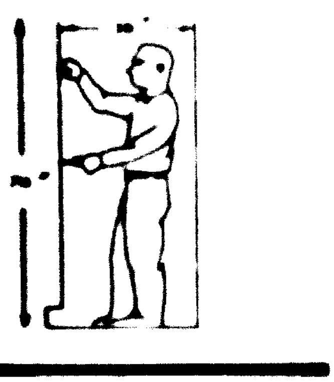
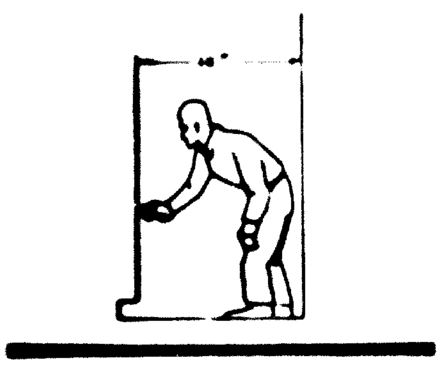
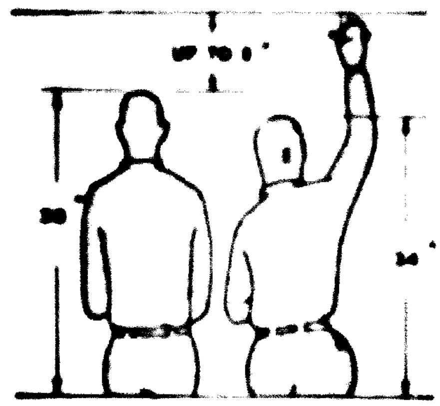


Fig.31









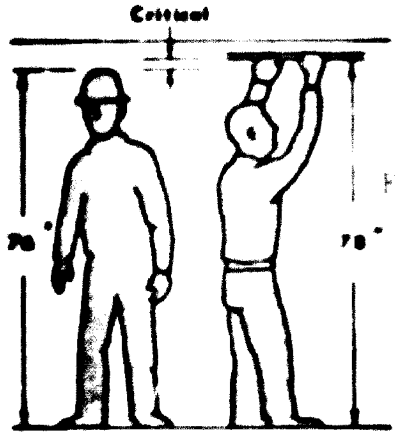
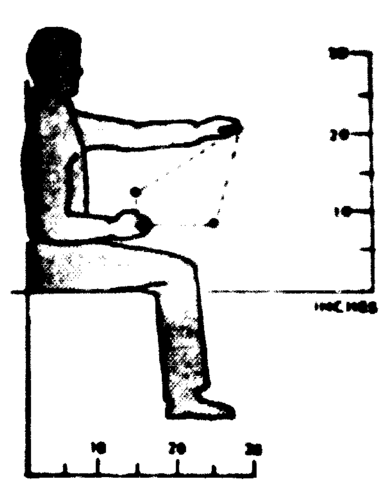


Fig.31 a



[illegible]

The first step in the design of engineering products is the recognition of a need and a general idea how to satisfy the demand. The next step consists in developing a research program based on a carefully conducted analysis of the market. This leads to the building of a model and the investigation of its performance. When these conditions have been met in a satisfactory manner, the full design follows with all details worked out, and the building of the product for distribution to customers.

Engineering design differs from many other design activities, such as the design of ornaments, fashion design etc. in that the physical parameters must be recognised that are basic in the design of industrial machinery, equipment and consumer goods.

In other words the design engineer must be well trained in both design and in the manufacturing methods that are available for converting the drawings into usable products.

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