Design of CNC Coordinate Table

Project Report

SUBMITTED BY

Ganesh .J

Sanil Babu K. V.

Senthil Nathan .S

Srinivas .M

Suresh M. R.

GUIDED BY

Mr. P. Suresh Prabhu, M.E.

1988-89

Faculty of Mechanical Engineering

Kumaraguru College of Technology

Coimbatore-641 006

Faculty of Mechanical Engineering

Kumaraguru College of Technology

Coimbatore-641 006

Certificate

Name .... Roll No. ....

This is the Bonafide Record of the Project titled

Design of CNC Coordinate Table

Done by

Mr. ....

In partial fulfilment of the requirements for the Degree of Bachelor of Engineering in Mechanical Engineering Branch of Bharathiar University, Coimbatore-641 046 during the academic year 1988-89

....

Head of the Department Staff in-charge

Submitted for the University Examination held on ....

University Register No. ....

....

Internal Examiner External Examiner

ACKNOWLEDGEMENTS

We are highly indebted to, and would like to express our heartfelt gratitude to Mr. P. Suresh Prabhu,B.E., for his support, guidance, inspiration and motivation over the past one year.

Thanks are also in order to our Principal, Prof. Rm. Lakshmanan B.E., M.Sc.,(Engg.), and Head of the Department of Mechanical Engineering, Dr. Ing. P. Vajravelu, for their suggestions and facilities rendered to us.

We are grateful to Mr. R. Sukumar, Divisional Manager, HMT. Ltd., Coimbatore for his thought provoking suggestions and valuable ideas. We are also indebted to Mr. S. Venkatraman, Consultant Engineer, PRICOL, Coimbatore, for helping us proceed with the design by giving us valuable information.

We are thankful to M/s. Lokesh Machines Limited, Hyderabad, for their constant guidance and encouragement given to us throughout this project.

Finally, We wish to express our deep gratitude to all the staff members and friends, whose constant encouragement and criticism has helped us complete this project with greater ease.

TABLE OF CONTENTS

SYNOPSIS

The project involves the design of a CNC Coordinate Table which is used for accurate positioning of predetermined coordinates. The CNC Coordinate Table is an improvement of the conventional Coordinate Table and its special features include Turcite lined guideways for more load carrying capacity, high precision ball screws for linear motion, specially designed bearing cartridge unit for ball screw support, permanent magnent d.c. servo motors as drives, linear encoders as feedback devices and a two axis CNC system.

The different phases involved in the design of the CNC Coordinate Table are as follows:

a) The Turcite lined guideways are designed based on the forces acting and material properties of Turcite and cast iron.

b) The high precision THK ball screws are selected based on table traverse, mounting distance, critical speed and buckling load.

c) Specially designed FAFNIR bearing cartridge units are selected for high axial stiffness and ease of assembly.

d) INDRAMAT permanent magnet d.c. servo drives are selected based on torque calculations.

e) Linear encoders are selected based on position accuracy and table traverse.

f) A Kirloskar CNC system is selected based on type of control required and the number of axis.

Thus the CNC Coordinate Table which incorporates high precision machine elements, can be used effectively for obtaining high precision components and higher productivity.

INTRODUCTION

The appearance of microprocessor based Computer Numerical Controlled (CNC) systems has brought about rapid progress in the machining of sculptured surfaces and in the manufacture and design of machine tools. Computers have now become a vital part of automation. They control stand-alone manufacturing system, machine tools etc. The increasing use of computer based systems in machine tools have enhanced the production process and has contributed to the increase of productivity.

The two axis CNC Coordinate Table being independent of the machine tool with which it is used, will help job machining. The CNC Coordinate Table is a sophisticated auxillary equipment for a machine tool where the latest features of the Computer Numerical Controls are integrated with a Coordinate Table.

A Coordinate Table is an accurate device for positioning or location of a point in the coordinate system. A conventional 2 axis Coordinate Table will locate a point by normal rotation of hand wheels. A CNC Coordinate Table locates a point on the coordinate system with much more simplicity and is more advantageous as regards accuracy and speed of positioning as compared to the conventional one.

High degree of operational sophistication of CNC Coordinate Table traversing in X and Y directions, needs some special constructional features worth mentioning.

The Coordinate Table is made up of three main components:

(1) The table top

(2) The intermediate member

(3) The base

All are made of high grade cast iron of ISI grade GCI 15.

The slides of the Coordinate Table are driven by variable speed d.c. servo motors with constant torque. These permanent magnet d.c. servo motors are coupled to the high precision ball screws using suitable couplings. In all, there are two ball screws and each is coupled to a motor, one in the X-axis motion and the other in the Y-axis motion. These high precision ball screws are suported by specially designed bearing cartridge units. The guideways are lined with Turcite. The linear encoders are mounted for effective feed back requirements.

In addition to these constructional features of Coordinate Table, a microprocessor unit is added to convert it into a CNC Coordinate Table. Hence a CNC Coordinate Table suitable for two axis positioning controlled by CNC System can be very effectively used on rigid standard Radial Drilling machines or Column type Drilling machines for wide varied range of applications involving accurate coordinate setting for operations like drilling, boring, reaming, counter boring, counter sinking, tapping etc., in components like heat exchanger plates, motor casings, automobile components etc.

By making use of this versatile CNC Coordinate table, there can be a complete elimination of drill jigs, scribing, marking out etc.

The other important advantage of this CNC Coordinate Table is easy installation on existing machine tools, moveable to other machine tools, less non-productive time, reduction in inspection time, comparatively less skill requirement, higher productivity and high repeatitive accuracy.

This CNC Coordinate Table can be adapted to other machining operations like milling, contouring, profile cutting etc., by interfacing this with a more flexible CNC System which incorporates the added features such as circular interpolation, continuous path control etc., and also by changing the table dimensions accordingly.

CHAPTER - 3

GUIDE WAYS

3.1 Introduction and requirements:

The basic function of guide ways is to ensure that the machine tool operative element carrying the workpiece or cutting tool moves along a predetermined path, generally a straight line. The major requirements the guide ways need to satisfy are:

(i) To give exact alignment of the guided parts in all positions and under the effect of operational forces.

(ii) There are to be means for compensating for possible wear.

(iii) There must be ease of assembly and economy in manufacture i.e. possibility of adjusting the alignment in order to allow for manufacturing tolerances.

(iv) Effective lubrication must be possible.,

(v) Good damping properties.

(vi) Low value of frictional forces acting on the guide way surface to ensure less wear.

Based upon the nature of friction between the contacting surfaces of the guide ways and operative element, guide ways can be classified as:

(i) Guide ways with sliding friction - slideways.

(ii) Guide ways with rolling fiction - antifriction ways.

In our design, we go in for guide ways with sliding friction.

3.2 Types of Slideways:

Depending upon the lubrication conditions at the interface of contacting surfaces the friction between the slideway surfaces may be described as:

(i) dry

(ii) semi-liquid

(iii) liquid

Here, as we go in for a layer of Turcite B (1.5mm thick) between the 2 contact surfaces which requires a permanent layer of lubricant between them, the category of slide way comes under the third type.

Design of Slideways:

They are distinguished by a relatively high coefficient of friction between the sliding surfaces. This results in considerable wear, reducing life as well as adversely affecting the machining accuracy. For proper functioning of slideways it is, therefore imperative that the friction be kept as low as possible by ensuring that a certain minimum amount of lubricant is always present between the sliding surfaces. This is why we use a layer of 'Turcite B' between the sliding surfaces (reduces friction to a large extent).

The combination of several flat slideways is often used for transmitting high supporting forces on long slideways. Play adjustment or wear compensation is not automatic as in the case of vee slides and it is therefore necessary to provide an adjustable strip.

This can either have parallel faces, being adjustable by means of laterally arranged screws or it can be wedge shaped and adjustable by longitudinal displacement. More over as the tightening screws must keep the strips in position, it is possible that during the longitudinal movement , the screws will loose unless they are secured by lock nuts, in order to avoid excessive stressing of the adjusting screws

3.4 Calculations

Assumptions Made :

1.	Maximum load on table	:	500 kgf.
2.	Size of the table	;	630 x 630 mm.
3.	Specific gravity of material of table	:	7.2×10^{6} kgf/mm^3
4.	Approximate weight of motor	:	25 kgf.
5.	Stroke	:	(250+250)mm=500mm.

a) Width of top saddle :-

Let the width of topsaddle be 'x' mm.

The volume of top saddle, V = (630 x 55 x 630) + (40 x 40 x 630) + (55 x 40 x 130) + (90 x 95 x 100) - [(13 x 32 x 630) + (19x18x630)] x 10 + (25 x70 x 350) + (25 x 70 x 550) = 20778100 mm^3

Weight of Top Saddle :

= (20778100 x 7.2×10^{-6}) kgf = 150 kgf

Total weight = (500 + 150)kgf = 650 kgf

Area of contact = (630 x X x 2)/100

= 12.6 x cm^2

Mean pressure on guideway :

CASE : CI to CI Contact

650/12.6x = 3.75 kgf/cm^2

This mean value of mean pressure on guideway is obtained from page 526 of CMTI data book.

Therefore x = 13.75 mm

CASE 2 : When Turcite B is used

$650/12.6x = 10$ kgf/cm^2

Therefore x = 5.15 mm.

For a height of 40 mm of the saddle, we choose a width of 80 mm. from page 530 of CMTI data book.

b) Width of bottom guideway

Let the width of bottom guideway be 'x' mm. Then the volume of the top saddle bottom

= (40 x 100 x 1200)x2 + (65 x 63 x 1200)x2 + (57.5 x 32 x 1200) x2+ (28 x 93 x 400) + (147 x 28 x 400) + (100 x 60 x 400) + (60x727.5x400) + (35 x 40 x 400)x2 + (62.5 x 100 x 400) + (175x28x400) + (28x65x400) + (117.5 x 7.5 x 400) + (100 x 7.5 x 400) + (87.5 x 92.5 x 100)

= 53361837.5 mm^3.

Therefore weight of bottom guide way

= $(53361837.5 \times 7.2\times10^{-6})$ kgf.

= 400.21 kgf.

Total weight = weight of bottom guide way + weight of motor

= (400.21 + 25) kgf

= 425 kgf

Total weight acting on bottom guide way

= 425 + 650 kgf.

= 1075 kgf.

Area of contact = 400 x X x 2

= 800x mm^2 = 8x cm^2

MEAN PRESSURE ON GUIDEWAY

CASE 1 : CI to CI contact

$$1075/8x = 3.75 \text{ kgf/cm}^2$$

Therefore $x = 35.8$ mm

CASE 2 : When Turcite B is used :

$$1075/8x = 10 \text{ kgf/cm}^2$$

$$x = 13.4 \text{ mm}$$

For a height of 40 mm of the saddle, we choose a width of 80mm from page 530 of CMTI hand book.

CHAPTER - 4

BALL SCREWS

4.1 An Introduction:

A ball screw is well described by its name: it is a lead screw that runs on bearing balls. The screw thread is actually a hardened ball race. The nut consists of a series of bearing balls circulating in the race and carried from one end of the nut to the other by return tubes. The Balls provide the only physical contact between the screw and nut, replacing the sliding friction of the conventional lead screw with a rolling motion. The substitution of rolling contact for sliding metal-to-metal contact minimises starting friction and eliminates the tendency for stick-slip when a slow smooth motion is desired.

The high efficiency (about 90 per cent) achieved with rolling contact devices permits the employment of anti-backlash methods. Another advantage of the ball-bearing lead screw is the extended life of the screw compared with the conventional one. It also eliminates the need for frequent compensating adjustments for wear, since due to the rolling contact, very little dimensional change occurs over the life of the lead screw.

4.2 ADVANTAGES OF BALL SCREWS AS AGAINST LEAD SCREWS:

(A) HIGHER EFFICIENCY:

Since sliding friction is replaced by rolling friction, efficiency is greater than 90% and the driving torque is less than one-third of that of conventional screws.

(B) LESSER HEAT GENERATION:

Even high load causes minimum heating up which means an improvement of positioning accuracy.

(C) NO STICK-SLIP:

Substituting a rolling contact for the sliding metal-to-metal contact minimises starting friction and eliminates the stick-slip tendency when a slow linear motion is required. In machine tool slide applications, this can result in a tremendous increase in "tool life".

(D) **HIGHER SERVICE LIFE:**

Due to the rolling friction, service life is considerably increased.

(E) **PRECISE POSITIONING:**

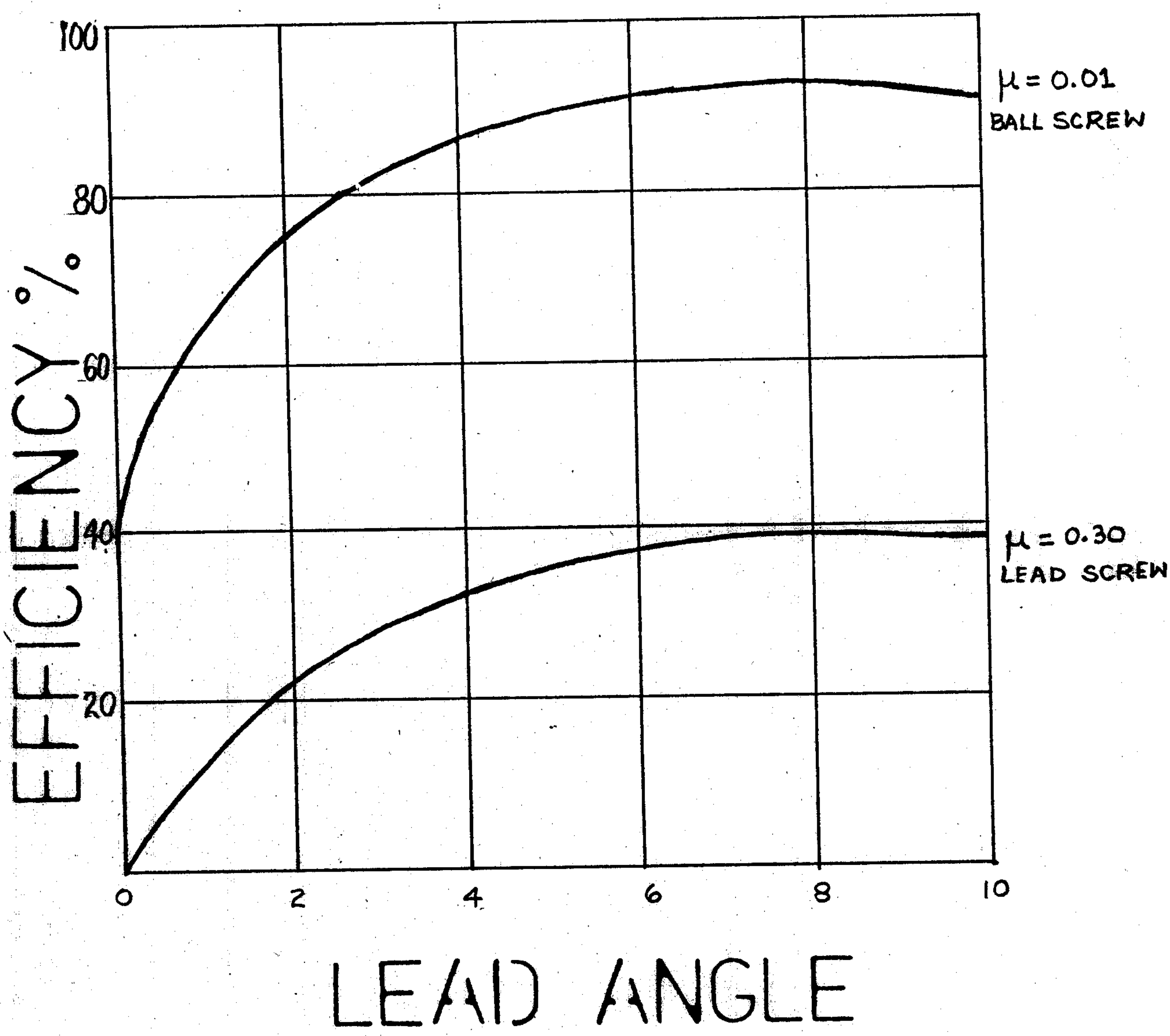
High positioning accuracy is possible even at low speeds.

(F) **MAXIMUM AXIAL STIFFNESS:**

Ball screws can easily be adjusted backlash free and preloaded for increasing the axial stiffness, response and repeatability of positioning.

(G) **HIGH POWER TRANSMISSION:**

Transmission of greater forces or maximum driving power with low loss at minimum mounting dimensions, is another feature.



EFFICIENCY GRAPH

APPLICATIONS:

1. MACHINE TOOLS
2. INDUSTRIAL ROBOTS
3. AIRCRAFT AND AEROSPACE
4. WEAPON SYSTEMS
5. MATERIAL HANDLING EQUIPMENT
6. NUCLEAR REACTORS
7. RAIL ROAD EQUIPMENT
8. MEDICAL EQUIPMENT
9. PRINTING AND PAPER MACHINES

4.3 The distinguishing features of ball screws are:

1. Low coefficient of friction; it is of the order of 0.004 to 0.01 as compared to 0.1 - 0.5, which is typical of lead screws.

2. Higher transmission efficiency (2 -9 times) which is particularly marked at load values of the helix angle

of the screw (2° - 5°) that are typical of power screws.

(3) Friction force is virtually dependent of the travel velocity and the friction at rest is very small; consequently, the stick-slip phenomenon is practically absent, ensuring uniformity of motion.

(4) By preloading the assembly, clearences can be eliminated and the axial stiffness can be improved to achieve or even exceed the stiffness of a sliding friction power screw. It should, however, be noted that the axial stiffness of an unpreloaded ball recirculating power screw is less than that of an ordinary one.

The materials of the screw and nut must satisfy the following two requirements:

1. Hardness of about Rc - 60 of the working surfaces.

2. Minimum residual stress so that the initial accuracy of transmission is maintained

Both for screws and nuts, these requirements are met by:-

1. Low carbon (about 0.2%) alloyed steels SAE 8626 and SAE 4615 which are nitrided to a depth of about 0.5 mm, and

(2) High Carbon (about 1.0%) C) Chromium Steels which are hardened fully.

The nuts may also be made from bearing steel, alloyed structural steel containing approximately 1% each of Si and Cr, and case hardened steel.

4.4 CALCULATIONS

ASSUMED DATA :

MODULUS OF ELASTICITY (E)	$= 2.1 \times 10^4$ kgf/mm^2
CRITICAL SPEED (N_c)	= 800 rpm.
SPECIFIC GRAVITY OF BALL SCREW MATERIAL	$= 7.85 \times 10^{-6}$ kgf/mm^3
MOUNTING DEPENDENT COEFFICIENT FOR FIXED SUPPORT (λ)	= 3.927
MOUNTING DEPENDENT COEFFICIENT	= 2.0

1. Buckling Load :

$$P = (n \pi^2 EI)/l_a^2$$

Where l_a = mounting distance.

Assuming the diameter of the ball screw to be between 20mm and 40 mm, we choose the mounting distance from page 30 of THK ball screw catalog as:

l_a = 687.5 mm

$I = (\pi/64) \times d_1^4 mm^4$, where d_1 is the root diameter of the threaded shaft, mm.

Thrust acting vertically during machining operation (drilling), kgf $= 1.16KD(100S)^{0.85}$ (From page 640 of CMTI data book).

Where k = material factor = 1.5 for cast iron (from page 651 of CMTI data book)

D = drill dia = 20 mm

S = feed perrevolution = 0.35 mm/rev.

$\therefore$ Thrust = 750 kgf.

Therefore Buckling load = $(F + \mu w)$ kgf.

$= (750 + 0.05 \times 1075) = 803.75$ kgf.

≈ 805 kgf.

Therefore

$$805 \text{ kgf} = (2 \times \pi^2 \times 2.1\times10^4 \times (\pi/64) \times d_1^{\,4})/(675)^2$$

Therefore $d_1 = 11.58$ mm

From page 38 of the THK catalog, we select a ball screw with a single flange double nut type with a root diameter of 29.2mm and a threaded shaft outer diameter of 32 mm and a pitch of 5mm; BNFN 3205-5.

2. CRITICAL SPEED

$$N_c = (60\lambda^2/2\pi l_b^{\,2}) \times [\,(E \times I \times g)/\gamma \times A\,]^{0.5}$$

Where g = acceleration due to gravity

$= 9800\ \text{mm/sec}^2$.

A = Sectional area = $(\pi/4)d_1^{\,2}$

l_b = Mounting distance = 662 mm

Therefore

$$800 = [\,60 \times (3.927)^2/2 \times \pi \times (662)^2\,] \times [\,(2.1\times10^4 \times (\pi/64) \times d_1^{\,4} \times 9800)/(7.85\times10^{-6}) \times (\pi/4) \times d_1^{\,2}\,]^{0.5}$$

= 1.933 mm

Since the value of root diameter determined by using the buckling load is greater, we proceed using that value of the root diameter.

RIGIDITY OF SUPPORT BEARING :

For Angular contact ball bearing :

$K_B = 1010 \times 10^2$ kgf/mm.

(From Fafnir bearing chart)

Therefore the rigidity K of the feed screw shafting is obtained from

$$1/K = 1/K_S + 1/K_N + 1/K_B$$

$$= 1/20455.13 + 1/110000 + 1/101000 \text{ kgf/mm}$$

$$K = 14732.01 \text{ kgf/mm}$$

LIFE CALCULATION

Life as Rotation :

$$L = (C_a/(f_w.F_a))^3 \times 10^6$$

Where L = life as rotation, rev

C_a = Basic dynamic load rating, kgf.

F_a = axial load, kgf.

f_w = Load factor = 1.2 from tables.

$$\therefore \quad L = (1450/(1.2 \times 805))^3 \times 10^6$$

$$= 3.38 \times 10^6 \text{ rev.}$$

CHAPTER - 5

BEARINGS

5.1 INTRODUCTION: ANGULAR CONTACT BALL BEARINGS are used due to its property to take radial loads as well as relatively large axial loads in one direction. The FAFNIR bearings are specially designed in cartridge units for ball screw support application.

The important features of this Bearing units are high axial stiffness, low drag torque, manufactured to super precision limits, precise control of axial runout, lubricated and sealed for life unit, low operating temperature, ease of assembly, possibility of checking alignment and running torque of assembled ball screw and bearing arrangement prior to assembly on to the machine.

These ball screw support bearings have a contact angle of 60°.

These bearing units do not require any additional lubrication. Each unit is prepacked with high quality bearing grease selected on the basis of extensive comparative tests. All risks of subsequent over-greasing or the use of incompatible lubricants are therefore eliminated.

5.2 CALCULATIONS

$$T_E = Y \times T$$

Where T_E = equivalent thrust load

Y = load factor = 1 from Fafnir bearing charts

T = Total thrust load

= (750 + 0.05 x 1075) kgf.

= 805 kgf

Therefore T_E = (1 x 805) kgf

= 805 kgf.

CHAPTER - 6

DRIVES

6.1 INTRODUCTION:

Parallel to the growth of machine tools, an equally rapid progress has been made in the field of electric motors. A bewildering variety of electric drives are available today, so that the task of the application engineers is steadily on the increase. The best machine is naturally the one in which there is proper coordination between the various elements.

The advent of automation has made the modern machine tools a highly sophisticated piece of equipment. Judicious combinations of electro-magnetic, electronic etc., circuits have been evolved to realise fast response and extreme flexibility of control. Electronic adjustable controls have made great inroads into the field of machine tools. (Mainly the drives consist of a D.C. motor with electronic circuits to control the armature and field).

The power devices commonly used in electrical control systems are a.c. and d.c. servo motors. A.C. servo motors are best suited for low power applications. They are rugged, light in weight and have no brush contacts as in the case with d.c. servo motor. However for large power applications like heavy drives etc., d.c. systems are an ideal choice on account of the availability of rugged high power amplification rotating and static amplifiers.

Mainly the drives consists of a d.c. Motor with electronic circuits to control the armature and field. D.C. motors allow precise control of the speed over a wide operating range by manipulation of the voltage applied to the motor.

D.C. DRIVES

D.C. servo motors offer high power O/P relating to their playgrid size. They combine high torque capability, high acceleration and low inertia for optimum system response.

They operate on the principle that a conductor carrying an electric current within a magnetic field is subjected to a force. DC Series motors control also uses comparatively simple and reliable control electronics readily available at a relatively low cost.

A constant voltage is applied to the motors causing it to rotate. When it is sensed that the motor is rotating too fast, the voltage is switched off. When the motor speed begins to fall, the voltage is re-applied. Thus, pulses or bursts of in-put signal are continuously applied to the motor in such a way as to control its speed. This technique is known as PULSE WIDTH MODULATION. For a high motor speed the voltage will be switched on for a longer period of time than it will be switched off. Conversely, for a low motor speed, the voltage will be switched off for a longer period than it will be switched on. Reversing the voltage polarity causes the motor to rotate in the reverse direction.

D.C. servo motors for robotic applications normally come in complete compact unit comprising of the motor, encoder/tachogenerator and fail safe braking.

Some brushless design DC motors which exhibit high torque/low speed characteristics can be used as direct drives. This eliminates need for and the problems associated with mechanical speed reduction elements. Such motors have starting torque, some three or four times that of continuously rated torque capability because they employ rare earth magnets with their construction.

6.2 SELECTION: Two basic considerations are involved in fixing the size of the motor:

i) the motor should be capable of delivering the load torque requirement and

ii) the temperature rise of the motor should be within the safe value for the insulation class.

Hence in the selection of a D.C. drive for our Coordinate Table, it is very much essential to find the driving torque of the feed screw systems.

6.3 FEATURES :Good Feed drives must possess the following features:

i) Continuously variable speed range of the order of 1:10,000 which means a feed motor rated for a maximum speed of 200 rpm (say) must run smoothly at a speed of 0.2 rpm without any waviness.

ii) Fine speed regulation and positioning accuracy even for the smallest distance element of 1 - 2 μm which represents an angular rotation of approximately 2 - 5 angular minutes.

iii) Good command transient response which allows minute contour deviations and ensures good surface finish.

iv) Good disturbance transient response to ensure short setting time after changes in load, and to keep position deviations as small as possible.

v) Minimum dimensions and weight, enabling direct mounting of servo motor on the ball screws.

6.4 CALCULATIONS

1. Frictional torque due to external load

$$T_p = F_a . l/(2 \pi \eta)$$

Where F_a = axial load $F + \mu w$

$= (750 + 0.05 \times 1075)$ kgf = 805 kgf.

l = lead = 5 mm = 0.5 cm

η = efficiency = 0.9

Therefore $T_p = (805 \times 0.5)/(2 \times \pi \times 0.9)$ kgf cm

= 71.17 kgf cm

= 0.07117 Nm

2. Frictional torque due to preload

$$T_D = K \times F_{a0} \times l/ 2\pi$$

Where K = internal frictional coefficient of preloaded nut

= (0.1 to 0.3)

l = lead = 0.5 cm

F_{a0} = 1/3 axial load

= 1/3 x 805 kgf = 268.3 kgf.

Therefore $T_D = (0.2 \times 268.3 \times 0.5)/2\pi$

= 4.27 kgf cm = 0.00427 Nm.

3. Load torque due to acceleration

$$T_J = J_m . \omega = J_m (2\pi n/60t)$$

Where T_J = load torque due to acceleration.

J_m = Moment of inertia acting on the motor.

$= J_3 + J_4 + w/g\ (1/2 \times N_1/N_2)^2$

and $J_3 = (\Pi \times \gamma_3 \times L \times d^4)/32g$

Where J_3 = moment of inertia of ball screw, kgf cm-sec^2

γ_3 = weight per unit volume = 7.85×10^{-3} kgf/cm^3.

L = Overall threaded shaft length = 70 cm

d = Threaded shaft diameter = 3.2 cm

g = acceleration due to gravity = 980 cm/sec^2

Therefore

$J_3 = 5.75 \times 10^{-3}$ kgf cm sec^2

and J_4 = moment of inertial of motor

= 0.0765 kgf cm sec^2 (from motor catalog)

Therefore

$J_m = 5.75 \times 10^{-3} + 0.0765 + (1075/980)\ (0.5/2\Pi \times 1)^2$

$= 0.0892$ kgf cm sec^2.

and $T_J = 0.0892\ (2\Pi n/60t)$

Where n = speed of motor shaft = 2000 rpm

t = time for acceleration = 8.1×10^{-3} sec.

(from motor catalog)

$T_J = 0.0892\ (2\Pi \times 2000/60\ /\ 8.1 \times 10^{-3})$

= 2306 kgf cm

= 2.306 Nm.

Total torque $= T_p + T_D + T_J$

= (0.07117 + 0.00427 + 2.306)Nm

= 2.38144 Nm.

The torque of motor is equal to 2.38 Nm which is approximately equal to 2.5 Nm. So we select 5.5 Nm 2 pulse control, Indramat permanent magnet d.c. servo drive.

CHAPTER - 7

FEED BACK FOR A CNC COORDINATE TABLE

7.1 INTRODUCTION AND SELECTION

We go in for a closed loop system for better accuracy. Here, the feed back to the computer (Up) is given by a Linear Encoder. The generation of pulse in the encoder is as follows. There is a glass scale with opaque lines and transparent spaces of equal width and interval. There is a scanning unit which comprises of a source of light, condenser lens for collimating the light beam, scanning recticle with under gratings and Silicar Solar Cells. When the scale is moved the lens and spaces coincide with the under gratings. The corresponding fluctuations in light are sensed by the solar cells which generate two sinusoidal output signals and a reference mark signal. The 2 signals are phase shifted by 90°.

These waves are subsequently transformed into square waves by semi triggers and logically gated such that the two pulse trains are 90° phase shifted and reference pulse available as O/P. The measuring step depends upon the interpolation factor (X5, X10), (∴ measuring step 1/(4X5), 1/(4X10))

Now we should calculate the number of pulses generated for a a distance 'x'. This is to be programmed into the computer ($\mu\varphi$). Therefore, for the distance of pulse generated

$$1 \text{ cm} = \frac{Y}{X}$$

Therefore, for whatever distance is to be moved, the appropriate number of pulses is to be calculated and when this number is reached, the motor voltage should be cut off.

CHAPTER -8

CNC SYSTEMS

8.1 INTRODUCTION:

A NC system is one in which actions are controlled by direct insertion of numerical data at some point. The input information for controlling the machine tool motions is provided through punched paper tapes or magnetic tapes in coded language. A CNC system is a self contained N.C. system which employs a computer to control the machine tool and it eliminates much of the hardware circuits. The use of software based CNC system to that of hardware based NC system brings an increase in system flexibility and an improvement for collecting part programs using the CNC Computer.

In the computer, the information is arranged, manipulated and stored in the form of binary words. In the CNC computer, each bit (binary digit) represents 1 BLV (Basic Length Unit). In a CNC computer, the part program is stored in the memory before the operation starts. During the machining, the control program of the CNC uses the stored part program to command the machine.

Every control system may be designed as an open or closed loop system. The term open loop control means that there is no feed back and the action of the controller has no information about the effect of the signals that it produces. The closed loop control measures the actual position and velocity of the axis and compares them with desired references. The difference between the actual and the desired values is the error. The control is designed in such a way as to eliminate or reduce to a minimum, the error, namely, the system is of a negative feed back type.

Considering the Coordinate table, one needs a CNC system which can effectively control the movements in two axis. If the Coordinate table is to be used as a positioning device for a drilling machine, then point to point control is adopted. Here the system would require only position counters for controlling the final position of the tool upon reaching the point to the drilled.

The main advantage of a closed loop incremental PTP system over the open loop control is that in an open loop system there is no information regarding the actual motion of the table. This can be remedied by mounting feed back transducers i.e. a linear encoders to the table. The functioning of the closed loop incremental PTP system is described as shown in figure 8.1:

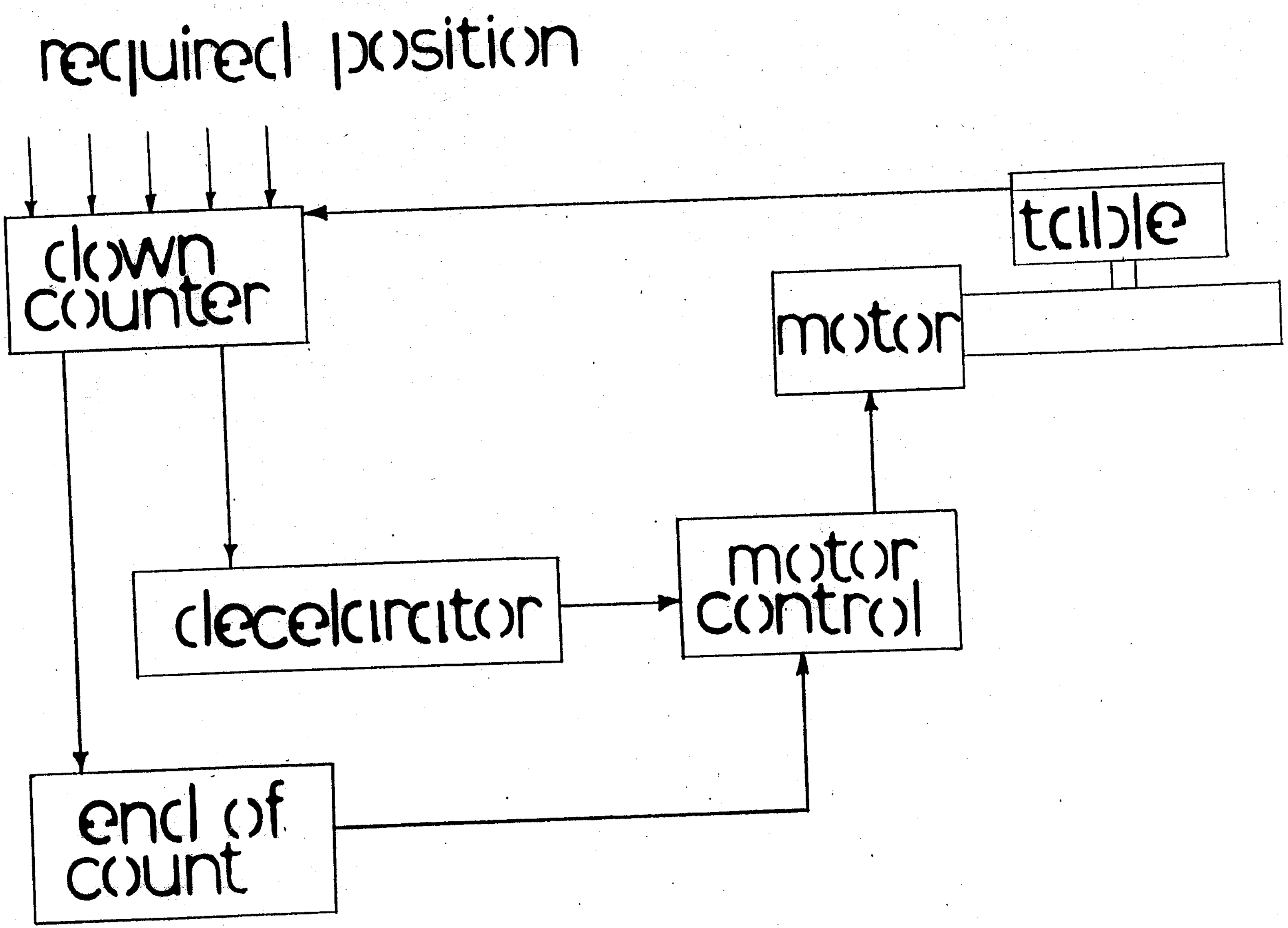
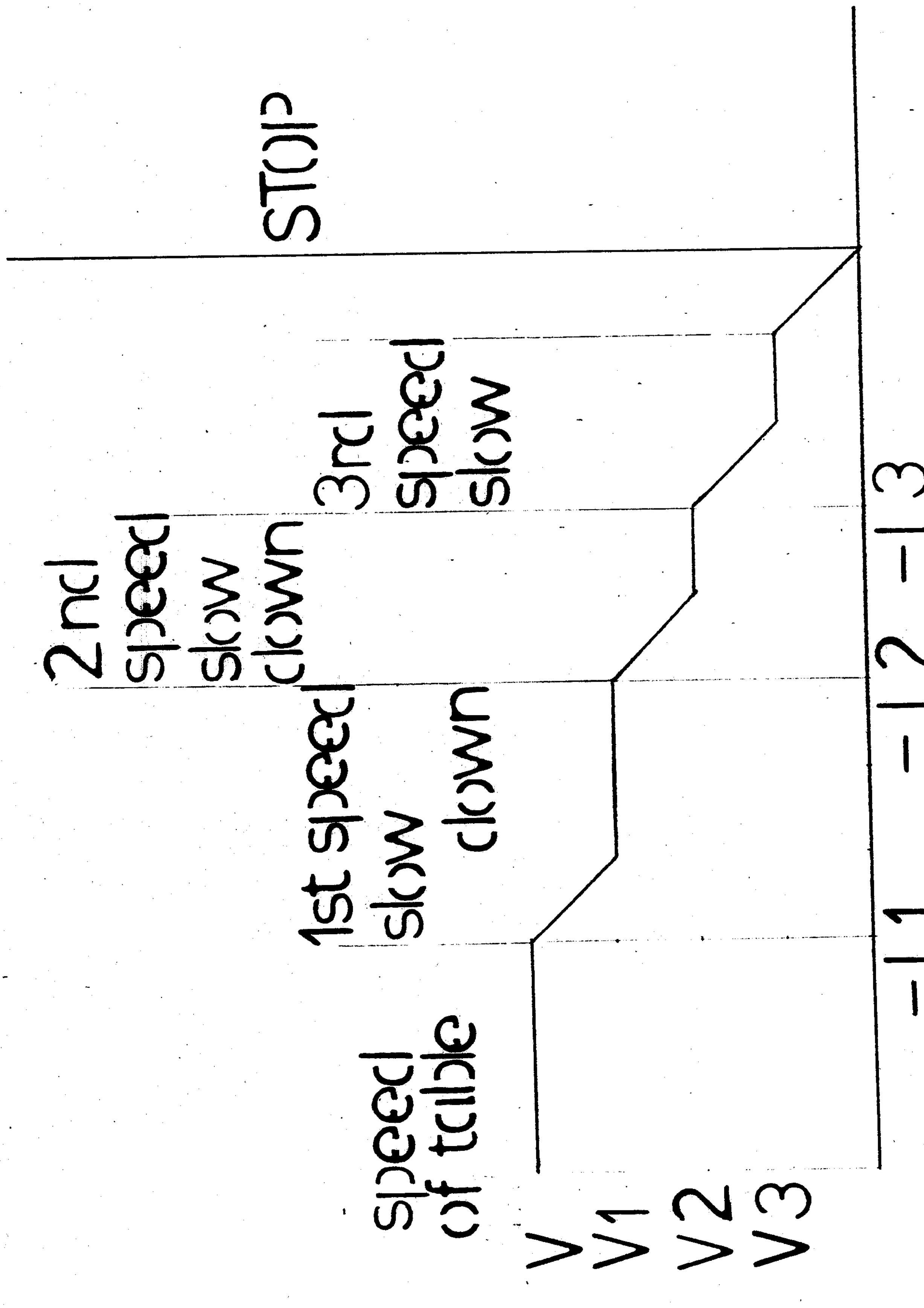

required position
down counter
table
motor
decelarator
motor control
end of count

Fig 8.1

The down-counter is loaded to the required incremental position, which resets the end-of-count circuit and allows the motor to rotate. The down counter is fed by the linear encoder pulses which represent the actual motion, rather than by command pulses which are produced by the pulse generator in the open loop system. The motor rotates as long as the contents of the counter is not zero namely as long as the required position is not reached. Upon reaching the desired position the zero contents of the counter activate the end-of-count circuit which in turn stops the motor. The decelerator circuit slows the motor before the target point in order to avoid overshoot.

The deceleration diagram is considered for one axis of the table. The table moves at a rapid velocity V until reaching a distance L1, from the target point where the table is instructed at a smaller velocity V. After a time delay, which depends upon the system inertia, the table moves at the new velocity VI until reaching a distance of L2 units from the target point, where again the velocity is reduced to V2. When the table is at a distance of L3 units from the target point the velocity is reduced once more and the table creeps towards the final point at a very low velocity V3 and subsequently stops.


STOP
3rd speed slow
2nd speed slow down
1st speed slow down
speed of table
L1
L2
L3
V
V1
V2
V3

8.2 SELECTION: For the Coordinate table of our specification, we have found the COMMANDO CNC system, manufactured by KIRLOSKAR ELECTRIC COMPANY LTD., in technical collaboration with Anilam Inc., USA, to be the ideal system and which bears the following specification:

SPECIFICATION:

* Two axis Microprocessor CNC
* Closed loop positioning
* Machinist language programming
* Full manual control with continuous jogging
* 16K program memory storage
* Straight line sequential positioning
* Decimal point programming
* Absolute/Incremental programming
* Programming from the drawing or from the component
* Mirror image facility
* Metric/inch conversion of both dimensions and feed rate
* Pattern repeat facility
* Self diagnostics with selected error codes
* Battery back-up

* Actual position display of all axes simultaneously
* Command display of all axes simultaneously
* Full editing facility with event search/event enter/event clear/add/delete features
* Optional selectable resolution of 0.01mm/0.0005"
* Off line programming
* Programme storage on casette (simple single push button operation)
* RS 232 C interface part (option) for paper tape
* Programmable light auxiliary functions (option).

CHAPTER - 9

ADVANTAGES

The principal advantages of CNC coordinate table are as follows:

- no drill jigs required
- no scribing or marking out
- less non-productive time
- faster positioning
- fewer errors - less scrap
- quick change over
- high accuracy and long life
- heavy, robust construction
- easy to install on existing machines
- moveable to other machine tools
- low initial cost compared with alternative CNC arrangements.

Thus to summarise, the CNC coordinate table offers many distinctive advantages which enhances the production process in a machine shop.

APPLICATIONS

The CNC coordinate table is a versatile machine which can be easily installed under an existing machine tool, such as the radial drilling machine. Since the use of drill jigs is eliminated, the CNC coordinate table is an excellent choice for a shop floor which has to manufacture a number of jigs for different types of components. Hence any production unit which spends a lot of money on drill jigs can go in for a CNC coordinate table. Moreover the time and trouble involved in the manufacture of drill jigs is eliminated.

A typical example of this CNC coordinate table is the machining of heat exchanger plates, where a number of holes are to be drilled with close tolerences and various diameters depending upon the capacity of the heat exchangers.

Another example is the machining of motor casings and automobile components.

MODIFICATION

The CNC coordinate table under consideration has been designed for a drilling machine and hence point to point control system was adopted. However, if the table is to be used under a milling machine, one can replace the existing CNC system with a continous path CNC system. In this type, contouring or profile machining is possible, thus dispensing the use of a CNC milling machine.

In this coordinate table, the linear encoder has been used. If the cost is to be reduced, one can go in for a rotary encoder which is directly coupled to the ball screw. Moreover, by reducing the dimensions of the table and the traverse, the machine will become more flexible to be adapted to any drilling or milling machine.

BIBLIOGRAPHY

1. THK LM SYSTEM BALL SCREW CATALOG

2. HEIDENHAIN GENERAL CATALOG

3. MACHINE TOOL DESIGN - N.K. MEHTA

4. CMTI HAND BOOK

5. P.S.G. DESIGN DATA BOOK

6. CAD/CAM - MIKELL P. GROOVER

7. COMPUTER CONTROL OF MANUFACTURING SYSTEMS - YOREM KOREM

8. DESIGN OF MACHINE TOOL ELEMENTS - KONEIGSBERGER

9. ROBOTICS AND AUTOMATED MANUFACTURING - YANTIAN

10. MACHINE TOOL DESIGN; VOL 3 - N. ACHERKAN

11. FAFNIR BEARINGS - SPECIALLY DESIGNED CARTRIDGE UNITS FOR BALL SCREW SUPPORT APPLICATIONS

12. INDRAMAT D.C. SERVO DRIVES, SERIES MDC 1 CATALOG.

COST ESTIMATION

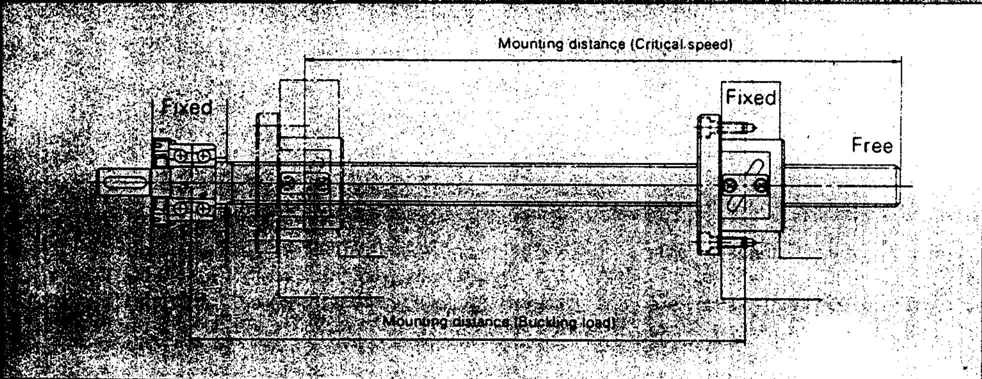
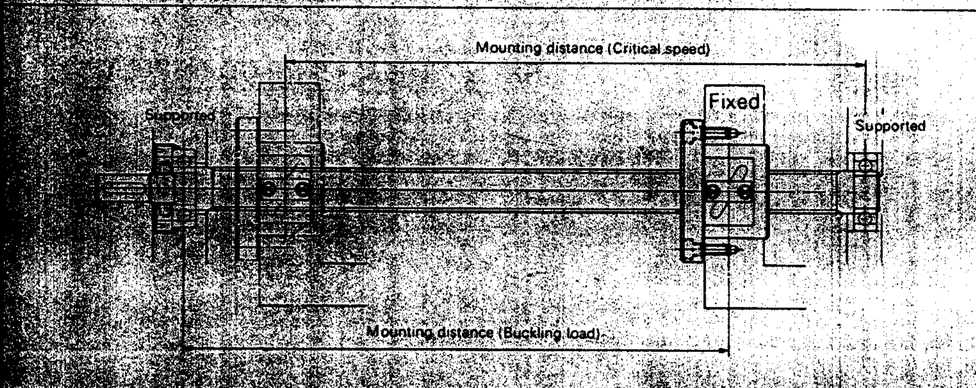
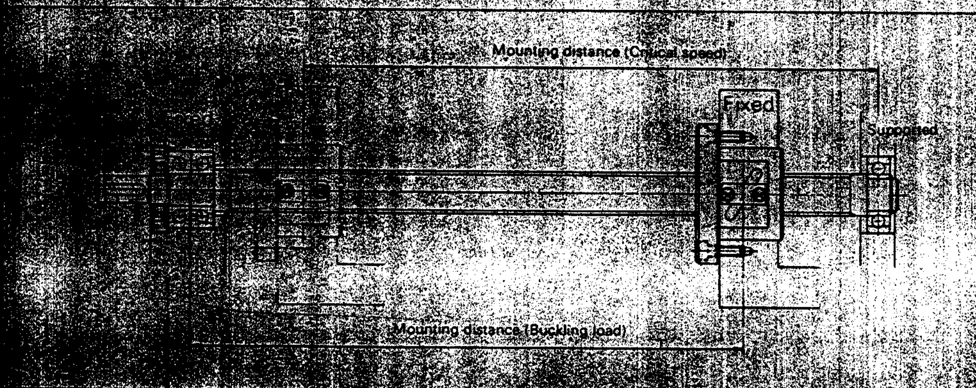
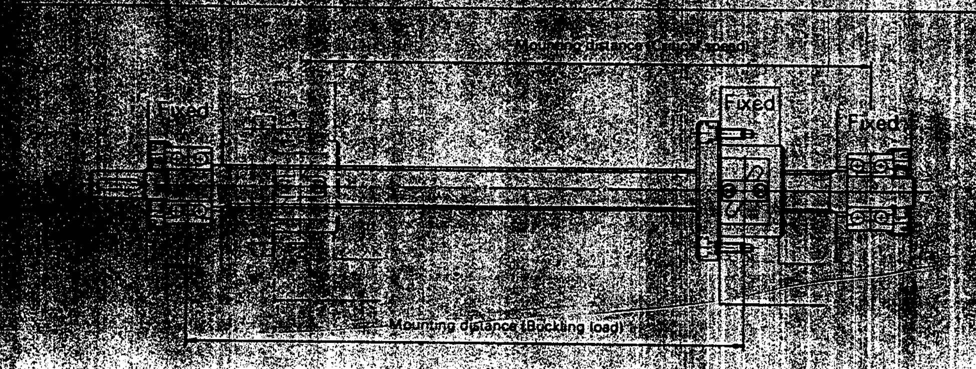
A.	Weight of Top member	= 200 kg
	Weight of Intermediate member	= 400 kg
	Weight of base	= 450 kg
	Total weight	= 1050 kg
	Cost of raw material	= Rs.12/kg (Cast Iron)
	Cost of all three members	= Rs.(12 x 1050)
		= Rs. 12,600
B.	Time for planing operation	= 20 hrs.
	Cost per hour of planing	= Rs. 80
	Total planing cost	= Rs. 1,600
	Time for milling operation	= 20 hrs.
	Cost per hour of milling	= Rs. 50
	Total-milling cost	= Rs. 1,000
	Time for surface grinding	= 8 hrs.
	Cost per hour of grinding	= Rs. 70
	Total grinding cost	= Rs. 560
	Time for scrapping	= 8 hrs.
	Cost per hour of scraping	= Rs. 30
	Total scraping cost	= Rs. 240
	Other machining expenses	= Rs. 3,000
	Total machining expense	= Rs. 6,400
C.	Cost of 32 mm dia ball screw of the required length	= Rs. 50,000 (2nos)
	Cost of D.C. drives	= Rs. 60,000 (2nos)

Selection of Precision Ball Screws

1. How to Mount Threaded Shaft

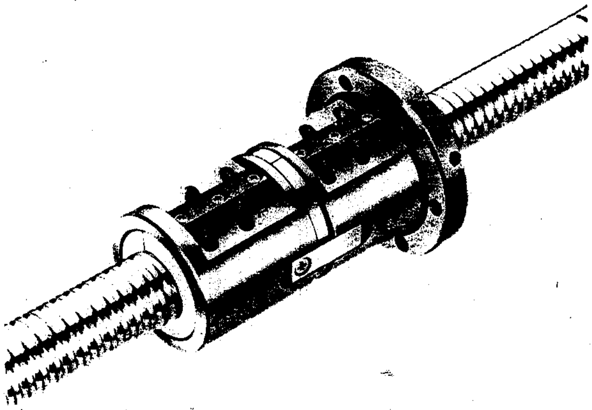
There are four typical methods of mounting threaded shafts. Since the allowable axial load and the allowable rotational speed will vary depending on the mounting method, much care should be used if severe working conditions and high accuracy are required.

Table 6

[illegible]	Typical applications
	• Low-speed rotation • Small shaft length
	• Ordinary mounting • Medium-speed rotation
	• Medium-speed rotation • High accuracy
	• High-speed rotation • High accuracy

THK Type BNFN

(Single-Flange Double-Nut)



<Note>

(1) Seal

The nut length varies depending on whether the product is sealed or nonsealed. Use the designation to specify whether a seal is required or not.

(2) Rigidity

The value of rigidity shown below indicates the spring constant obtained from the load and elastic displacement measured at the application of a preload which is 10% of the basic dynamic load rating (Ca) and then an axial load which is three times the preload amount.

The value, however, does not include the rigidity of the parts related to nut mounting; normally, 80% of the value should be used as a rough standard.

If the preload (Fao) is different from 0.1 Ca, then the value of rigidity (KN) should be calculated by.

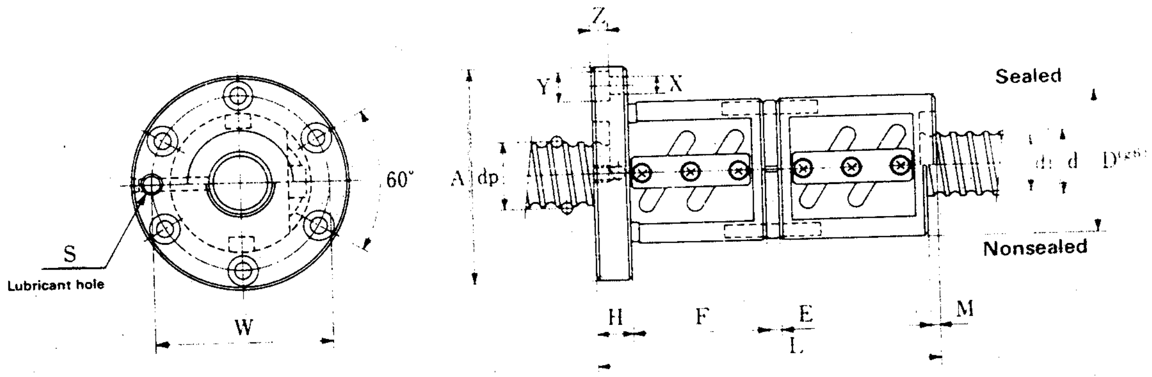
$$K_N = K\left(\frac{Fao}{0.1Ca}\right)^{\frac{1}{3}}$$

where

K : [illegible]idity value shown below.

Designation	Threaded shaft OD d	Lead l	Ball diameter Da	Ball circle diameter dp	Root diameter d_1	Number of circuits × Turns	Basic load rating Ca kgf	Coa kgf	Rigidity (Note 2) kgf/μm
BNFN 2506-3	**25**	**6**	3.969(5/32")	25.5	21.4	2×1.5	1230	3340	55
BNFN 2506-2.5	**25**	**6**	3.969(5/32")	25.5	21.4	2.5	1090	2790	50
BNFN 2506-5	**25**	**6**	3.969(5/32")	25.5	21.4	2×2.5	1760	5570	95
BNFN 2506-3.5	**25**	**6**	3.969(5/32")	25.5	21.4	3.5	1370	3900	65
BNFN 2508-3	**25**	**8**	4.763(3/16")	25.5	20.5	2×1.5	1580	3880	60
BNFN 2508-2.5	**25**	**8**	4.763(3/16")	25.5	20.5	2.5	1390	3260	50
BNFN 2508-3.5	**25**	**8**	4.763(3/16")	25.5	20.5	3.5	1700	4500	70
BNFN 2510A-2.5	**25**	**10**	4.763(3/16")	26.3	21.4	2.5	1330	3180	50
BNFN 2512-2.5	**25**	**12**	3.969(5/32")	26.0	21.9	2.5	1060	2750	50
BNFN 2516-1.5	**25**	**16**	3.969(5/32")	25.5	21.4	1.5	800	1800	35
BNFN 2805-3	**28**	**5**	3.175(1/8")	28.5	25.2	2×1.5	960	2990	65
BNFN 2805-2.5	**28**	**5**	3.175(1/8")	28.5	25.2	2.5	850	2490	55
☆**BNFN 2805-5**	**28**	**5**	3.175(1/8")	28.5	25.2	2×2.5	1380	4990	100
BNFN 2805-3.5	**28**	**5**	3.175(1/8")	28.5	25.2	3.5	1070	3490	75
BNFN 2806-2.5	**28**	**6**	3.175(1/8")	28.5	25.2	2.5	850	2490	55
☆**BNFN 2806-5**	**28**	**6**	3.175(1/8")	28.5	25.2	2×2.5	1380	4990	100
BNFN 2806-7.5	**28**	**6**	3.175(1/8")	28.5	25.2	3×2.5	1830	7480	145
BNFN 2806-3.5	**28**	**6**	3.175(1/8")	28.5	25.2	3.5	1070	3490	75
BNFN 2808-3	**28**	**8**	4.763(3/16")	28.5	23.6	2×1.5	1620	4330	65
BNFN 2808-2.5	**28**	**8**	4.763(3/16")	28.5	23.6	2.5	1420	3610	55
BNFN 2808-5	**28**	**8**	4.763(3/16")	28.5	23.6	2×2.5	2310	7220	105
BNFN 2810-2.5	**28**	**10**	6.350(1/4")	29.0	22.4	2.5	2090	4990	60
BNFN 3205-3	**32**	**5**	3.175(1/8")	32.5	29.2	2×1.5	1010	3420	70
BNFN 3205-2.5	**32**	**5**	3.175(1/8")	32.5	29.2	2.5	900	2850	55
☆**BNFN 3205-5**	**32**	**5**	3.175(1/8")	32.5	29.2	2×2.5	1450	5700	110
BNFN 3205-7.5	**32**	**5**	3.175(1/8")	32.5	29.2	3×2.5	1930	8580	165

- **Any type with the☆marks is a standard product which is available inexpensively.**
- **See page 7 for the configuration of the designation.**



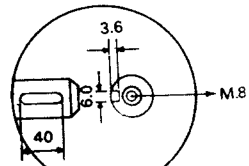
					Nut dimensions							
Outside diameter	Flange diameter				Total length		Hole P.C.D	Mounting hole			Lubricant hole	Designation
D	A	H	F	E	L	M	W	X	Y	Z	S	
53	76	11	42	7	110	3	64	5.5	9.5	5.5	M6	BNFN 2506-3
53	76	11	30	7	86	3	64	5.5		5.5	M6	BNFN 2506-2.5
53	76	11	48	7	122	3	64	5.5	[illegible]	5.5	M6	BNFN 2506-5
53	76	11	36	7	98	3	64	5.5	9.5	5.5	M6	BNFN 2506-3.5
58	85	15	51	8	135	5	71	6.6	11	6.5	M6	BNFN 2508-3
58	85	15	38	5	106	5	71	6.6	11	6.5	M6	BNFN 2508-2.5
58	85	15	46	5	122	5	71	6.6	11	6.5	M6	BNFN 2508-3.5
58	85	18	39	11	120	13	71	6.6	11	6.5	M6	BNFN 2510A-2.5
53	76	11	41	7	108	8	64	5.5	9.5	5.5	M6	BNFN 2512-2.5
53	76	11	39	9	108	10	64	5.5	9.5	5.5	M6	BNFN 2516-1.5
55	85	12	35	5	94	7	69	6.6	11	6.5	M6	BNFN 2805-3
55	85	12	25	5	74	7	69	6.6	11	6.5	M6	BNFN 2805-2.5
55	85	12	40	5	104	7	69	6.6	11	6.5	M6	☆BNFN 2805-5
55	85	12	30	5	84	7	69	6.6	11	6.5	M6	BNFN 2805-3.5
55	85	12	30	6	86	8	69	6.6	11	6.5	M6	BNFN 2806-2.5
55	85	12	48	6	122	8	69	6.6	11	6.5	M6	☆BNFN 2806-5
55	85	12	66	6	158	8	69	6.6	11	6.5	M6	BNFN 2806-7.5
55	85	12	36	6	98	8	69	6.6	11	6.5	M6	BNFN 2806-3.5
60	104	18	52	12	144	10	82	11	17.5	11	M6	BNFN 2808-3
60	104	18	40	8	116	10	82	11	17.5	11	M6	BNFN 2808-2.5
60	104	18	64	8	164	10	82	11	17.5	11	M6	BNFN 2808-5
65	106	18	55	5	146	13	85	11	17.5	11	M6	BNFN 2810-2.5
58	85	12	38	8	103	3	71	6.6	11	6.5	M6	BNFN 3205-3
58	85	12	26	5	76	3	71	6.6	11	6.5	M6	BNFN 3205-2.5
58	85	12	41	5	106	3	71	6.6	11	6.5	M6	☆BNFN 3205-5
58	85	12	56	5	136	3	71	6.6	11	6.5	M6	BNFN 3205-7.5

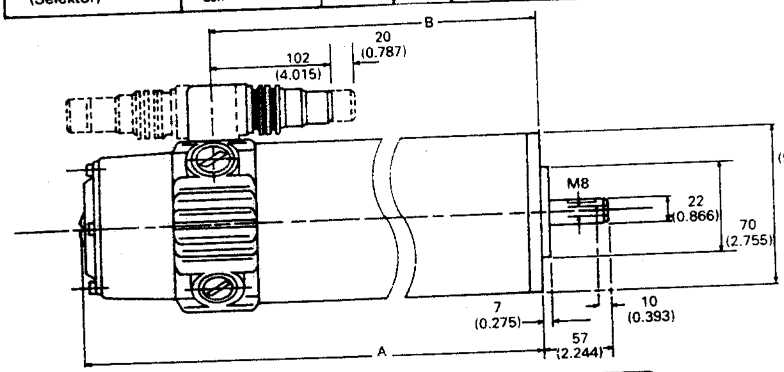
MOTOR PARAMETERS
Technical Data System Performance Zones
TENV Series

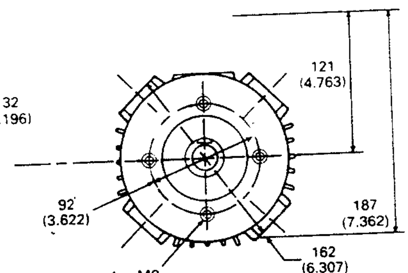
Parameter	Symbol and (Unit)	Motor Size MDC				Motor Size MDC		
		10.10H	10.20F	10.30D	10.40C	10.10H	10.20D	10.30C
D.C. Servo Motor		(n_{max} = 2000 [min^{-1}])				(n_{max} = 3000 [min^{-1}])		
Permissible continuous effective current[1]	I_{effzul} [A]	11	13	19	24	11	19	24
Maximum peak pulse current	$\hat{I}$ [A]	75	100	150	200	75	150	200
Torque constant[2]	K_m [Nm/A]	0,30	0,47	0,47	0,47	0,30	0,30	0,35
Voltage constant[2]	Cw [Vs/rad]	0,30	0,47	0,47	0,47	0,30	0,30	0,35
Armature resistance[2]	R_A [Ω]	0,50	0,40	0,24	0,17	0,50	0,19	0,15
Armature inductance	L_A [mH]	4,2	2,4	1,2	0,9	4,2	1,1	0,7
Rotor moment of inertia	J [kgm^2]	0,0030	0,0050	0,0075	0,010	0,0030	0,0050	0,0075
Mechanical time constant	τ_m [ms]	17	9	8,1	7,8	17	11	9
Maximum useful speed	n_{max} [min^{-1}]	2000	2000	2000	2000	3000	3000	3000
Permissible peak voltage	$\hat{U}$ [V]	170	170	170	170	170	170	170
Insulation class		F	F	F	F	F	F	F
Maximum ambient temperature	T [°C]	45	45	45	45	45	45	45
Thermal time constant	τ_{th} [min]	55	70	85	100	55	70	85
Weight	m [kg]	13	18,5	24	29	13	18,5	24
Short-circuit torque[2]	M_{dk} [Nms/rad]	0,18	0,55	0,92	1,26	0,18	0,47	0,82
Continuous torque (2pulse)[1]	M_{deff} [Nm]	2,5	3,7	5,5	8	2,5	3,5	5
Continuous torque (3pulse)[1]	M_{deff} [Nm]	3	4,5	6,3	9,5	3	4,3	5,7
Continuous torque (Selektor)[1]	M_{deff} [Nm]	3	5,5	8	10	3	5,2	7,3

Tachogenerator		
Voltage constant[2]	$C_{(1)}$ [Vs/rad]	0.317 ± 10% (= 33 V/1000 min^{-1} ± 10%)
Armature resistance[2]	R_A [Ω]	115
Minimum terminating resistance	R_L [Ω]	15,000
Ripple percentage	[%]	0.5
Electrically operated Brake		
Holding torque	M_B [Nm]	20
Nominal voltage	U_N [V]	+ 24 ± 10%
Winding resistance[2]	R_i [Ω]	47

1) Rise of 50°C in case temperature above ambient
2) at 20°C





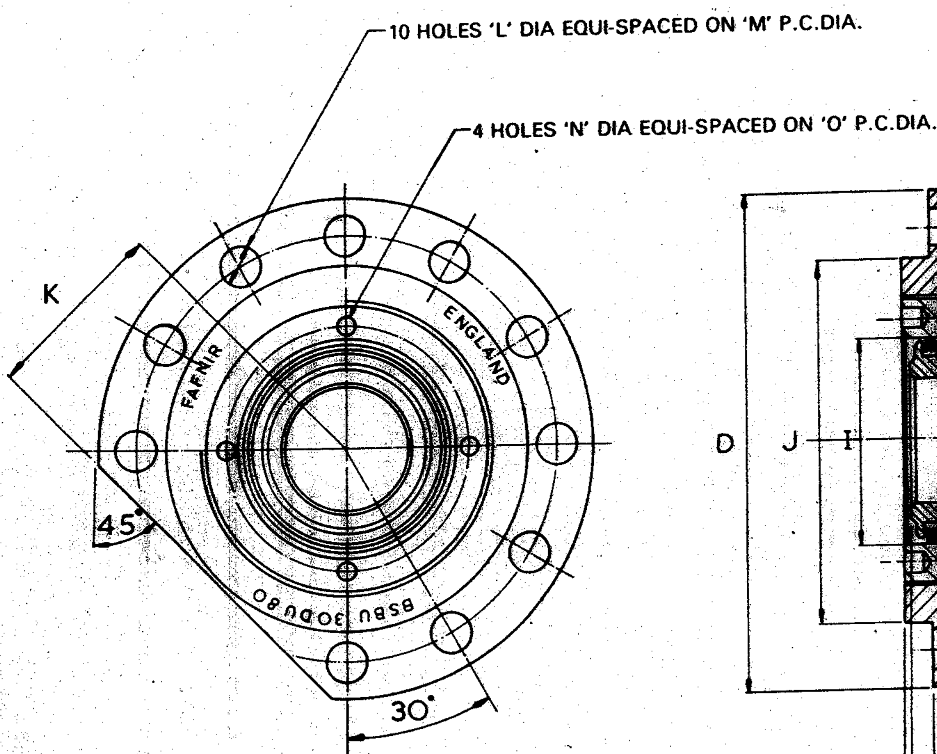


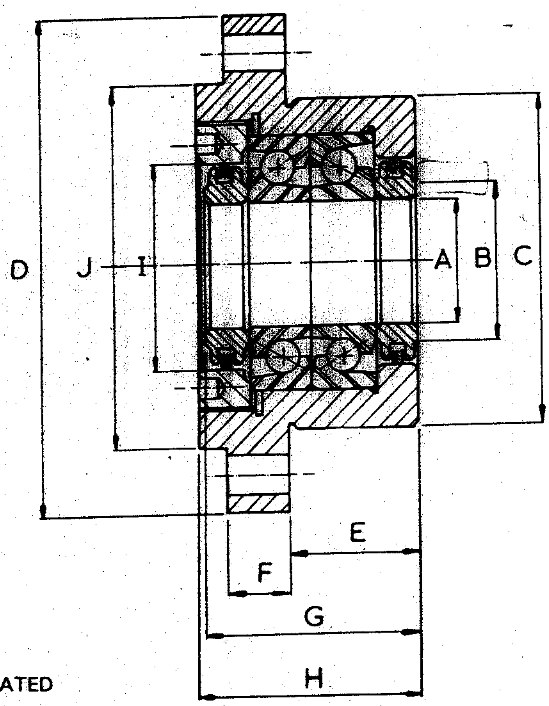
Dimension in mm (inches)

	MDC	10.10	10.20	10.30	10.40
Dimension 'A'	**without brake**	261	327	403	469
	with brake	276	342	418	484
Dimension 'B'		148	214	290	356

The design and manufacture of our products are subject to constant improvements. Hence, the above specifications and illustrations may vary slightly from the products supplied.

General Arrangement BSBU "DU" Series





RECOMMENDED SHAFT g5
DIMENSIONAL TOLERANCES ± 0,13 UNLESS OTHERWISE STATED

Data Table BSBU "DU" Series

SHAFT A M.M.	UNIT NUMBER	DIMENSIONS [± 0,13 U.O.S.] A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	LOAD RATING 'N' DYNAMIC TB	STATIC TO	DRAG TORQUE Nm	AXIAL STIFFNESS N/μm	AXIAL RUN-OUT μm	WEIGHT Kg	LIMITING SPEED MIN^{-1}
STANDARD SERIES																							
20	BSBU20DU60	20.000 19.996	26.0	60.000 59.987	90.0	32.0	13.0	44.260 43.240	47.0	36.0	64.0	32.0	6.6	76.0	4.3	42.5	17300	25000	0.34	710	2.5	1.1	3300
25	BSBU25DU80	25.000 24.996	40.0	80.000 79.987	120.0	32.0	15.0	50.260 49.240	52.0	50.0	88.0	44.0	9.2	102.0	4.3	59.5	20400	35500	0.46	1010	2.5	2.3	2300
30	BSBU30DU80	30.000 29.996	41.0	80.000 79.987	120.0	32.0	15.0	50.260 49.240	52.0	50.0	88.0	44.0	9.2	102.0	4.3	59.5	20400	35500	0.46	1010	2.5	2.2	2300
35	BSBU35DU90	35.000 34.995	46.0	90.000 89.985	130.0	32.0	15.0	50.260 49.240	52.0	60.0	98.0	49.0	9.2	113.0	4.3	66.5	25000	45500	0.46	1240	2.5	3.2	2000
40	BSBU40DU90	40.000 39.995	46.0	90.000 89.985	130.0	32.0	15.0	50.260 49.240	52.0	60.0	98.0	49.0	9.2	113.0	4.3	66.5	25000	45500	0.46	1240	2.5	3.1	2000
45	BSBU45DU92	45.000 44.995	55.0	92.000 91.985	130.0	[illegible]	15.0	50.260 49.240	52.0	66.0	98.0	49.0	9.2	113.0	4.3	66.5	26000	51000	0.52	1330	2.5	3.3	1900
HEAVY DUTY SERIES																							
35	BSBU35DU124	35.000 34.995	66.0	124.000 123.982	165.0	43.5	17.0	64.260 63.240	66.0	76.0	128.0	64.0	11.4	146.0	5.3	90.0	48900	79400	0.80	1400	2.5	6.3	1400
40	BSBU40DU124	40.000 39.995	66.0	124.000 123.982	165.0	43.5	17.0	64.260 63.240	66.0	76.0	128.0	64.0	11.4	146.0	5.3	90.0	48900	79400	0.80	1400	2.5	6.1	1400
45	BSBU45DU124	45.000 44.995	66.0	124.000 123.982	165.0	43.5	17.0	64.260 63.240	66.0	76.0	128.0	64.0	11.4	146.0	5.3	90.0	48900	79400	0.80	1400	2.5	6.0	1400
50	BSBU50DU124	50.000 49.995	66.0	124.000 123.982	165.0	43.5	17.0	64.260 63.240	66.0	76.0	128.0	64.0	11.4	146.0	5.3	90.0	48900	79400	0.80	1400	2.5	5.9	1400