STUDY ON DESIGN PARAMETERS OF HYDROSTATIC GUIDEWAYS IN BEAM AND SLIDE-REST FOR HEAVY DUTY CNC VERTICAL TURNING MACHINE

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Abstract: The main aim of this paper is to study about design parameters for hydrostatic guideways pads. In this pad there is working area which is called pockets. This pocket performs the bearing function. For this pressurised fluid is supplied to the entire pocket and spreads equally in gap between hydrostatic guideways and sliding ram and cross slide. The guideways is one of the important elements of machine tool. The main function of guideways is to make sure that the cutting tool or machine tool operative elements moves along pre-determined path. Hydrostatic guide ways are the one type of guide ways which comes under the fully lubricated guide ways systems. The main functions of hydrostatic guideways are to reduce were and tear of two mating parts and chatter in tooling and axis movement. This system required more maintenance because when oil goes out from HS guide way's pocket it will flow open in machine area, so there is change of mixing of dust and other parts and by this life of hydrostatic guideways reduce. Aim of paper is to study for design of hydrostatic guideways with having low maintenance and long cycle time.

Keywords: Hydrostatics, guideways, pad, pad force, loadability or load capacity, stiffness, friction, heating, oil demand, hydraulic pump and PM flow controllers.

Introduction:

The increase of demand to manufacturing complicated components of high accuracy in large quantities specifications and standardization, sophisticated technological equipment and machinery and machinery have been developed. These are high accurate due to their good design and new innovations in it.

Hydrostatic guideways represented one guidance types ensuring linear movements of machine tool. Hydrostatic guide ways are the one type of guide ways which comes under the fully lubricated guide ways systems .This technology is innovated during 1980s.This is used to give smooth motion to axis of tools or job .The main function of this devices is to reduce were and tear of two mating parts and chatter in tooling and axis movement. This technology is using in vertical Turing lathe for linear motions in Z-axis, guide ways in cross slide for X-axis AND guide ways in hydraulic ram for tooling.

Hydrostatic guideways system

- **Working principal:**

The hydrostatic guideways system is generally consict of hydrostatic pad, flow controller and hydraulic pump. The guideway system is made by more than one hydrostatic pad which ussaly operated by independent flow of hydraulic fluid in order to reach a static-state at various and variable loaded pads.

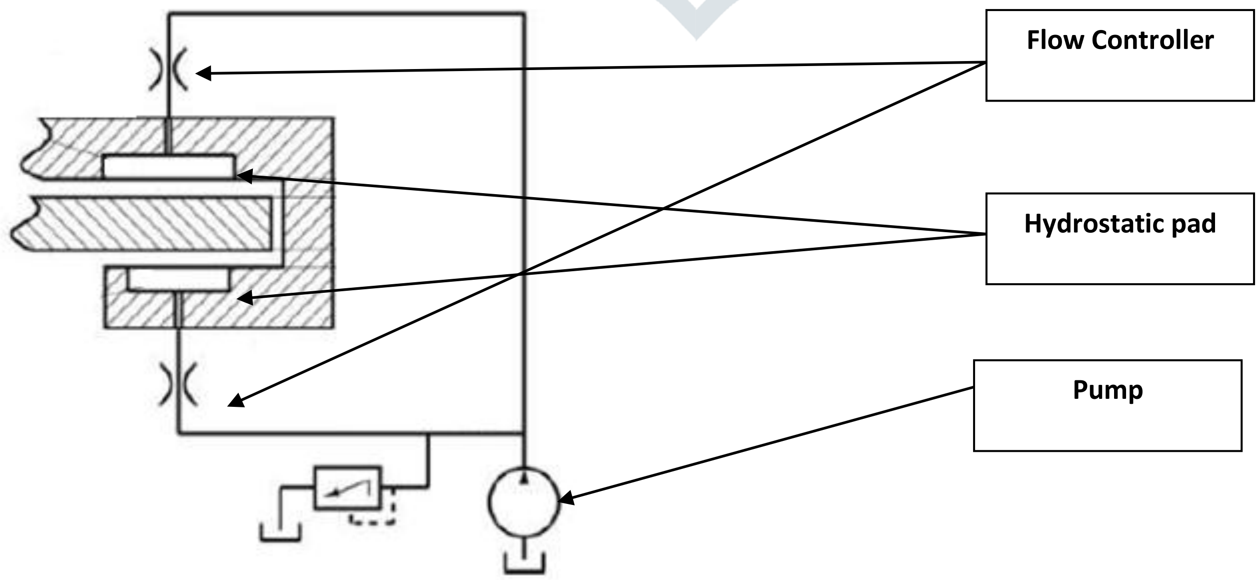


Fig. 1: Hydrostatic working diagram

Design parameters

- Fixed parameters: pump pressure, oil viscosity and one hydrostatic pad dimension;
- Free parameters: remaining pads, stiffness, flow rate, hydraulic pump and damping

- **Hydrostatic pad:**

The hydrostatic pad is the working area which works as bearing surface or guiding prism. It is rectangular or square in shape with cavity between it. During operation hydraulic fluid of known viscocity is supplied into the cavity which creates a region of constant pressure at higher speed. This pressurised fluid is fed into it by narrow hole in the cavity area which is connected by power pack through PM-flow controller. Between the pad and guiding prism the action of pressurized oil create a narrow height to flow pressurised oil outside the hydrostatic pad.

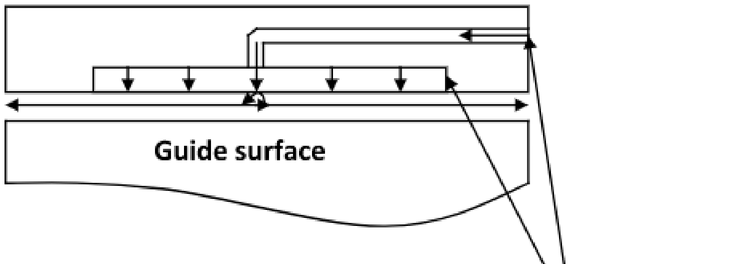


Fig. 2a: Hydrostatic bearing pad configuration

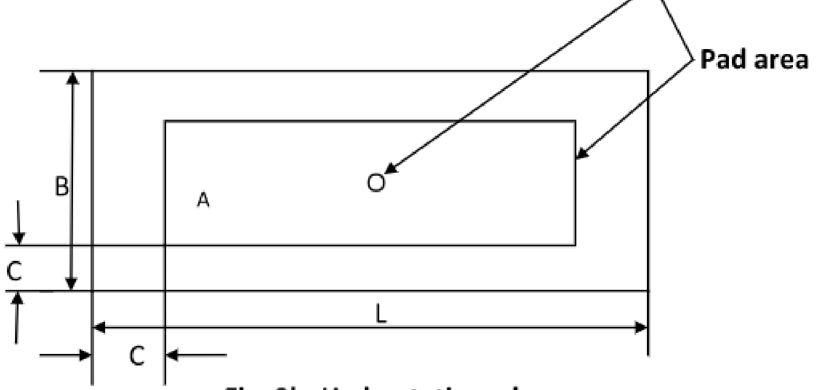


Fig. 2b: Hydrostatic pad

A= pad working area
B=width
L= length
A= BL-BC-LC
F = p × A (f is pad force, p is fluid pressure and A is pad working area)

- **Pad forces**

The force of the pads varies with the cutting forces and acceleration. To be sure that the pressure pads are always strong enough to carry the highest load without getting contact. During the calculation of forces in pad and pad pressure it is necessary to know structure because heavy duty CNC carries slide-rest, horizontal feed box and tool head, in which cutting force, gravity of tool head and some other loads are introduced.

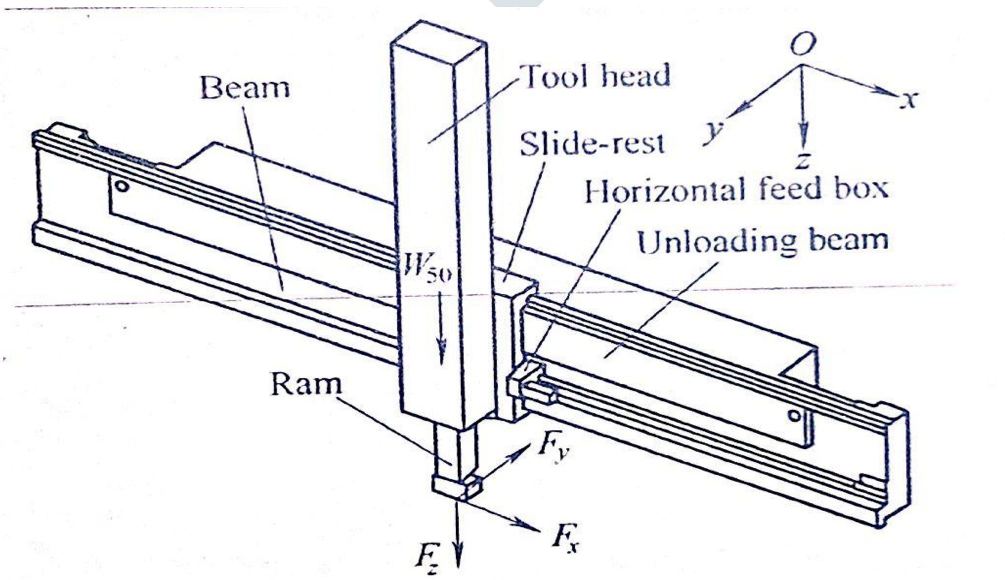


Fig.assembly model of feed system of heavy duty CNC vertical turning machine

*W*50 ——Gravity of tool head component
*W*53 ——Gravity of slide-rest and horizontal feed box component
Fx, *Fy*, *Fz* ——Components of cutting force in *x*, *y* and *z* directions
Fi ——Hydrostatic force of pocket *i*
*F*f *i* ——Friction force of pocket *i*
*F*s ——Action force of ballscrew against nut
*F*u ——Unloading force of unloading beam

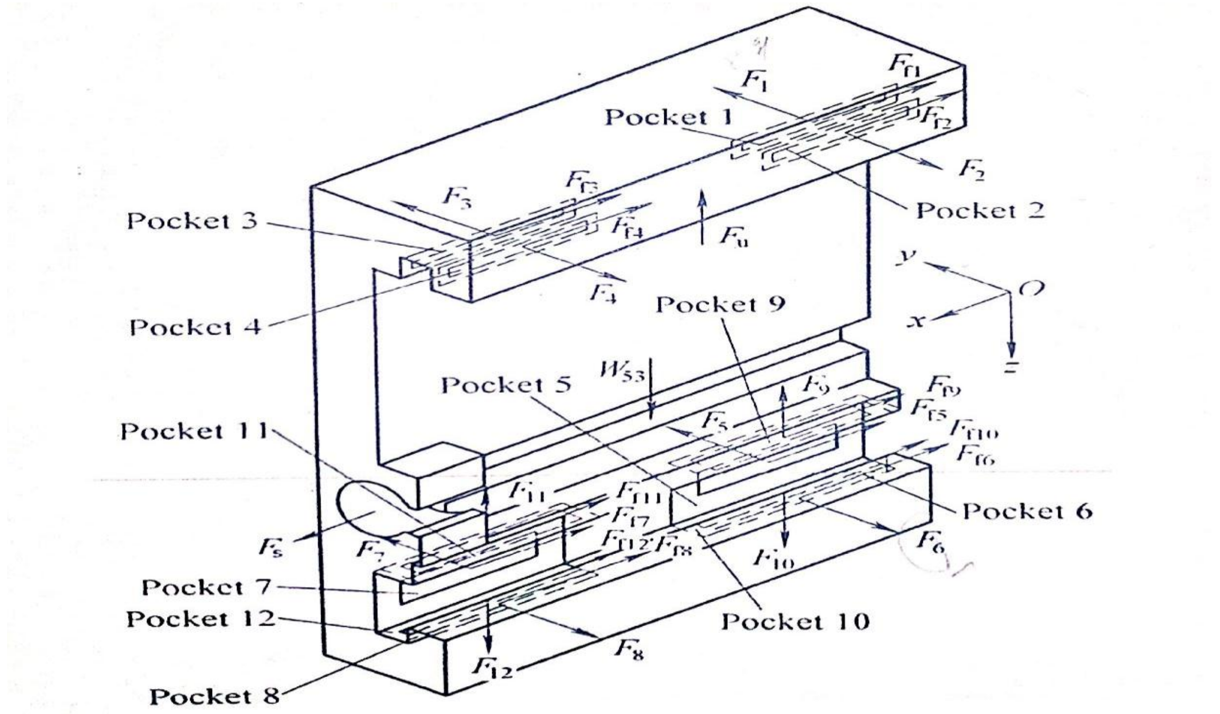


Fig.load and pad distribution of slide-rest

$F_x + F_s - \sum_{i=1}^{12} Fi1 = 0$
$F_y + \sum_{i=1,3,5,7} Fi - \sum_{i=2,4,6,8} Fi = 0$
$F_z + W_{50} + W_{53} - F_u - F_9 + F_{10} - F_{11} + F_{12}$
$\boldsymbol{F}_{yz} = (F_y \;\; F_z \;\; W_{50} \;\; W_{53} \;\; F_u \;\; F_1 \;\; F_2 \; .... \; F_{12})$
$\boldsymbol{F}_{xz} = (F_x \;\; F_z \;\; W_{50} \;\; W_{53} \;\; F_u \;\; F_9 \;\; F_{10} \;\; F_{11} \;\; F_{12} \;\; F_{f1} \;\; F_{f2} \; ...... \; F_{f12})$
$\boldsymbol{F}_{xy} = (F_x \;\; F_y \;\; F_1 \;\; F_2 .... F_8 \;\; F_{f1} \;\; F_{f2} .... F_{f12})$
***r**x* ——Vector composed of *yz*-plane projections of moment arms of the forces in ***F**yz* with respect to *F*s 's acting point
***r**y* ——Vector composed of *xz*-plane projections of moment arms of the forces in ***F**xz* with respect to *F*s 's acting point
r**z* —— Vector composed of *xy*-plane projections of moment arms of the forces in *xy* ***F with respect to *F*s 's acting point
Here f= coefficient of friction

- **Loadability or load capacity**

W= loadability or load capacity = $\frac{0.9 \times p \times A}{2}$
0.9 = coefficient of friction
P = flow of fluid in bar

- **Stiffness and gap**

k = 1.757 W/h
h = gap between sliding surface and pad i.e. 24µm
The pad pressure, stiffness and gap of the pads depend on the prestress and forces on the pockets. The prestress is adjusted on the pocket pressure at assembly.
The gap is between ideal parallel surfaces at pocket pressure. The play increase by the pressure in the pocket by part deformation. The lifting in right angle to the pad surface is reduced by the production errors. Stiffness is only of the hydrostatic pad gap. The play should be produced or adjusted.

- **Friction and heating**

$F_f = 2C(L + B - 2C)\eta \frac{V}{h}$
The friction energy is calculated with ideal parallel surfaces. Gaps with production errors will have a bit more friction, if there is no contact. Mechanic contact will result very high friction which is not allowed. The friction is influenced by the oil viscosity. The friction energy and the heating by the friction is proportional with square of speed.
At 0m/min there is a oil heating, by the pump energy, which heat the oil from 20^0C to about 26^0C depending on efficiency of the pump.

- **Oil demand**

Oil required in each pad is calculated with consideration of oil viscosity tolerance +/_10% and 20-%reverve at ma. Oil allowed temperature of 40^0C at input of PM-flow controller. It is noted that the pump will heat up the oil about 5^oC according to pump efficiency.

$Q = \frac{p}{6\mu}\delta^3 (A)$

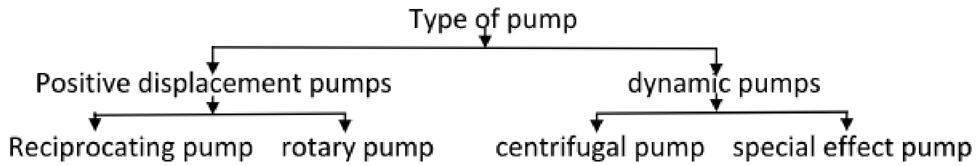
A= pad working area
B=width
L= length
A= BL-BC-LC
μ =Dynamic viscosity of the hydrostatic oil = $\vartheta \times \mu$

δ=Oil film thickness of pocket

a. flow is now multiply by 2 because there are two pads in one connection.
b. Calculation of flow with total number of pad
c. Total flow is calculated
d. Total fow multiply with 10 % for oil viscosity
e. Total flow multiply with 20% for oil viscosity
f. Add all and total oil demand is generated

- **Hydraulic Pump**

A pump is device used to move fluid, such as liquid or slurries or gas. A pump displays a volume by physical or mechanical action. Main purpose of pump is to circulate liquid around a system.



Calculation for power of electric motor

Power in kW = $\frac{pump\ flow \times working\ pressure}{612 \times geometric\ efficiency}$

Power in HP = power in kW × 1.3

- **PM flow controller:**

Permanent magnet flow controller is a type of a constant flow rate regulator which is based on feeding of oil in each pocket at constant flow which carried out by mean of a single pump for every hydrostatic pad. This type of regulation method is used in high loading capacity given by no restriction (usually capillary tube) of oil flow into hydrostatic pads. The oil pressure is limited by pm and pressure available on the pump, this method is energy efficient.

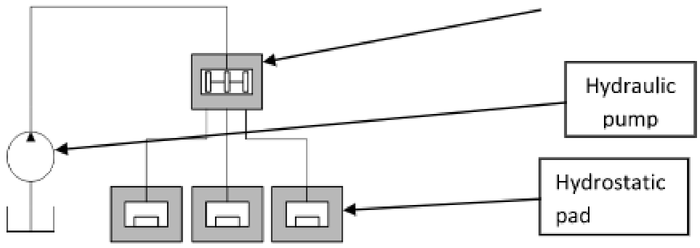


Fig. 3: PM flow controller diagram

The flow of fluid through the initial flow restrictor of the PM flow controller is always laminar, the flow of fluid through the controller and the hydrostatic pad change due to the varying fluid viscosity in a similar way. So the stiffness and load capacity along with the gap size and pad pressures remain constant, regardless of the fluid viscosity. The flow of fluid is controlled by the elastic deformation of the steel spring disc i.e., there are no sliding motions, the PM flow controller works without wear or hysteresis. Due to the low mass of steel spring disc and high regulating forces, the PM flow controller acts very quickly, with natural frequencies many times above the applicable energising frequencies. There are no sliding elements so the controller is also maintenance-free.

- **Advantages (Hyprostatik)**

1. Wear-free, even under maximum load, which means no loss of precision with increasing use,
2. Power of ten improvement in damping, resulting in considerably better workpiece surface finish and tool service life,
3. No fluctuations and variations in the friction, as is the case with rolling-element guides due to ball circulation,
4. No feed force backlash when the direction of motion is reversed,
5. Practically friction-free at low speeds, no stick-slip effect,
6. Capable of travelling less than 0.1 µm,
7. The sliding properties of the material, slide and guideway are unimportant – moulded mineral, aluminium or casting compound can be used.

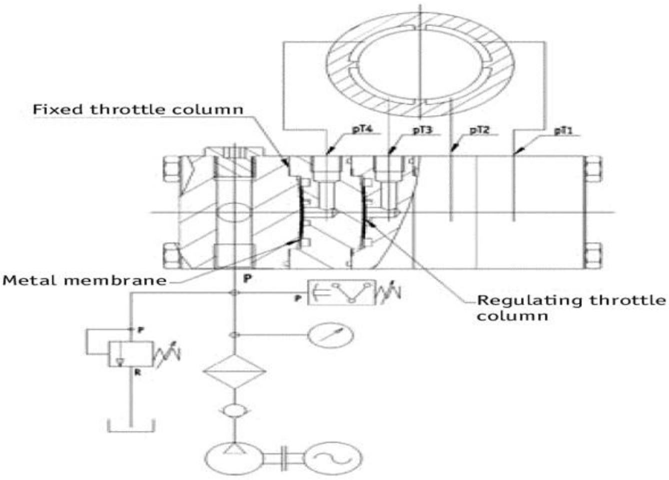
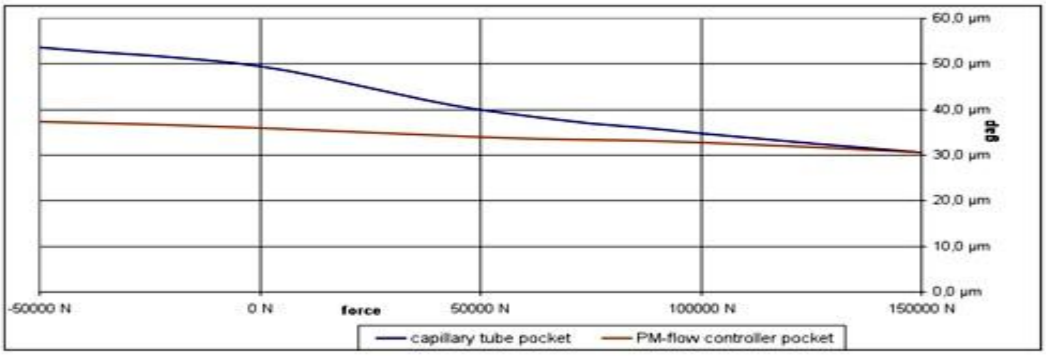


Fig. 4: PM flow controller (partially taken from Hyprostatik)

Comparison between capillary tube and PM-flow controller (Hyprostatik)

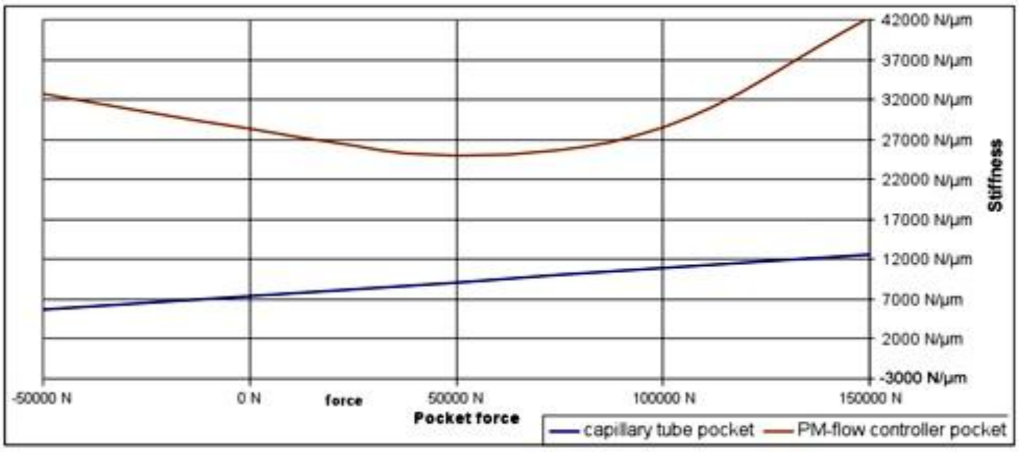
Compare capillary tube – PM-flow controller



force	-50000 N	0 N	50000 N	100000 N	150000 N
gap capillare	53,6 µm	49,4 µm	39,9 µm	34,8 µm	30,6 µm
gap PM-flow controller	37,4 µm	35,9 µm	34,0 µm	32,8 µm	30,6 µm

Table.1 Gap

Compare capillary tube – PM-flow controller



force	-50000 N	0 N	50000 N	100000 N	150000 N
stiffness capillare	5687 N/µm	7390 N/µm	9048 N/µm	10856 N/µm	12600 N/µm
stiffness PM-flow controller	32757 N/µm	28411 N/µm	24920 N/µm	28513 N/µm	42232 N/µm

Table.2 Stiffness

- **Result and future scope**

The paper discusses about the Hydrostatic Guideway, Pm flow controller and its parameters. Hydrostatic guidways have various advantages in heavy duty- machining application and it is maninly in high precision turning and milling applications, hydrostatic bearing improve surface quality and machining accuracy along with enlarging cutting capacities and speeds. They are also bentifitia by damping load at the point where the load is applied to resist against vibration produced in machine tools by blade contact shocks, tool wear, regenerative effects, and other disruptive but common forces

The hydrostatic guideways sytem with PM flow controller excels with high stiffness, better load carrying capacity and energy efficient because it have more throttling gap so it decrease the stiffness. Due to this PM flow controller in hydrostatic guideways is suitable for application where superior stiffness is required.

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