2017 International Conference on Computer Network, Electronic and Automation (ICCNEA 2017)

Study on The Mechanical Properties of Hydrostatic Guide-way

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***Abstract*—Hydrostatic guide-way is used on CNC machine tools because of its advantages. In order to meet the requirements of ultra-precision CNC machine tool for precision and high speed, a new type hydrostatic guide-way with high liquid resistance is put forward. The simulation has been done how the position, width and depth of the ring on oil seal edge of hydrostatic guide-way effect on the oil chamber pressure. It is verified that the chamber's pressure of hydrostatic guide-way can be enhanced significantly if the position, width and depth of the ring are appropriate. It is reasoned that the carrying capacity and stiffness of hydrostatic guide-way are improved when a ring is set on its oil seal edge. The conclusion can be got that the new type hydrostatic guide-way has a better carrying capacity and stiffness because of the ring if its position, width and depth are appropriate.**

Keywords-Hydrostatic guide-way; Oil film stiffness; Carrying capacity; High liquid resistance; Oil-pad

I. INTRODUCTION

The development of machining in ultra-precision, high-speed, nanotechnology and informatization has promoted the evolution of CNC machine tool. Hydrostatic guide-way are widely used in large, heavy-duty and super precision machining tool[1] because of the advantages such as good bearing capacity, better absorption vibration, proper stiffness and so on. How to improve the oil film stiffness of hydrostatic guide-way is becoming the main problem to improve the machining accuracy of machine tool, for which the fluctuation of oil film thickness from the change of load affect the accuracy of machine tool during application process. Many researches about features of hydrostatic guide-way have been done: references [2] and [3] analyzed the influence of oil chamber depth on guide-way performance; references [4] and [5] analyzed the effect of machining accuracy and parameter as the location of oil chamber on guide-way respectively. Oil thinness has been controlled through changing oil viscosity based on the relationship between capillary restrictor flows [6]. References [7] have research to improve the carrying capacity and stiffness of hydrostatic guide-way by designing a new type of resistive oil edge of it.

In this paper, in order to improve stiffness and carrying capacity of hydrostatic guide-way, a new structure of hydrostatic guide-way with high liquid resistance, which has an oil ring on oil seal edges, has been put forward based on local pressure loss. The simulation about the influence of oil ring structure parameters on oil film stiffness and carrying capacity of the hydrostatic guide-way has been done, and the experiment has done. The result from simulation and experiment show that the new hydrostatic guide-way proposed has played an active role in improving the carrying capacity of hydrostatic guide-way.

II. THE FACTORS OF INFLUENCING THE CARRYING CAPACITY AND STIFFNESS OF HYDROSTATIC GUIDE-WAY

An oil-pad of hydrostatic guide-way is composed by oil chamber and oil seal edges. Until now, most of oil seal edges is used parallel plate shown as Fig .1, which oil-film is circular. The pressures of oil-film is p_0, the gap is h_0. The oil flow can be expressed as follow:

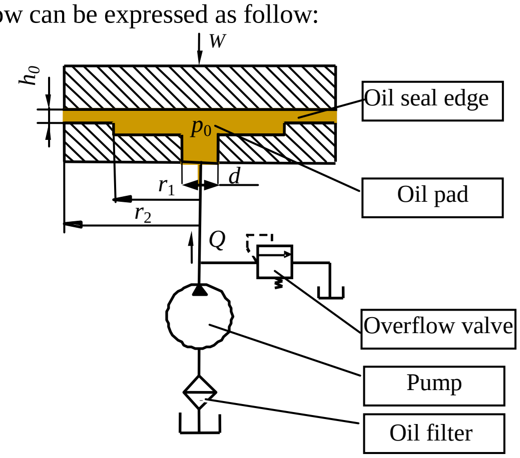


Figure 1. The schematic diagram for hydrostatic guide-way with quantitative oil supply

$$Q = \frac{p_0}{R_{h0}} \tag{1}$$

Where, R_{h0} is the liquid resistance designed and is presented as $R_{h0} = 6\mu \ln(r_2 / r_1)/(\pi h_0^2)$;

When W is loaded on slider of hydrostatic guide-way, the pressure of oil chamber changes because of the oil film thickness or the gap changing:

$$W = pA_e = \frac{p_0 A_e}{1+\lambda_0(1-\varepsilon)^3} \tag{2}$$

Here, p is oil chamber's pressure; A_e is the effective bearing area, A_e $=\pi(r_2^2-r_1^2)/2\ln(r_2/r_1)$; ε is the relative displacement between the guide surface, $\varepsilon=e/h_0$; λ_0 is the liquid resistance ratio, $\lambda_0=R_h/R_{h0}$. R_h is liquid resistance, $R_h=6\mu\ln(r_2/r_1)/(\pi h^2)$.

The stiffness of hydrostatic guide-way stiffness can be expressed as:

$$s = \frac{\partial W}{h_0 \partial \varepsilon} = \frac{3pA_e\lambda_0(1-\varepsilon)^2}{h_0[1+\lambda_0(1-\varepsilon)^3]^2} \tag{3}$$

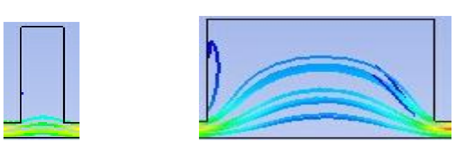
According to equation (2) and (3), the carrying capacity and stiffness of hydrostatic guide-way can be improved by increasing p or A_e. But increasing A_e will lead to increase the volume of hydrostatic guide-way or decrease the width of oil seal edge. The carrying capacity and stiffness of hydrostatic guide-way will be weak because of the chamber's pressure p when the width of oil seal edge is increased. The pressure p can be increased by increasing liquid resistance of hydrostatic guide-way from equation (1). It is inferred that the performance of hydrostatic guide-way can be improved through increasing liquid resistance.

III. Analysis on the Mechanism of Local Pressure Loss for a Ring

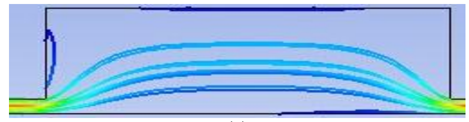
When oil flows through the channel with variable cross-section, its hydraulic energy is lost as the pressure being decreased gradually because of oil's viscosity. Therefore, pressure is related to not only the shape of channel but also the length of channel. While oil goes through the oil seal edge with ring of hydrostatic guide-way, two kinds of hydraulic energy losing will be occured: linear pressure loss and local pressure loss. A hypothesis is put forward that a ring set on the oil seal surface of the hydrostatic guide-way will improve the carrying capacity of hydrostatic guide-way.

A. The Effect of the Ring's Width on the Local Pressure Loss

For proving the hypothesis above, the simulation for streamline of the oil through the ring is done and the generation mechanism of local pressure loss is analyzed. The result is as Fig .2. Here the width of oil ring is changed.



(a) (b)



(c)

Figure 2. The influence of oil ring on the flow characteristics

It is found: while oil going through the channel, there is no enough length for local pressure loss if the ring's width is too small as (a). There is enough length for it if the width is increased as (b). Not only local pressure loss but also linear pressure loss will be caused if the width is too big as (c), but linear pressure loss decrease greatly because of the gap between oil seal edge increasing. The result is that the total pressure loss is decreased. So, the ring's width should be neither small nor large. Accordingly, its depth should be as same as its width.

B. The Effect of the Ring's Depth on the Local Pressure Loss

For analyzing the relationship between the local pressure loss and the ring's depth h_2, the model as Fig .3 is built and the pressure difference between inlet A and outlet B is simulated while h_2 being set as 0.2,0.5,0.8,1.0,1.3, 1.5mm, its width l_2 as 0.2, 0.5 and 0.8mm, l_1 as 0.1mm. The result is shown as Fig .4.

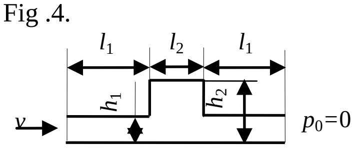


Figure 3. The Model of the Boundary Conditions for Parallel Plate with Oil Sink

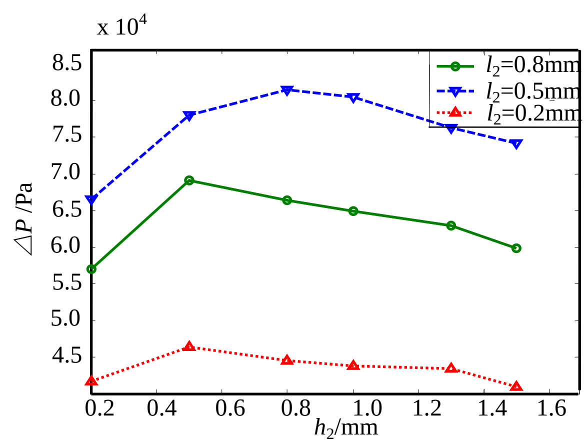


Figure 4. The Relationship between the local pressure loss and the ring's depth

It is found that local pressure loss is the highest when l_2=0.5 and h_2 is from 0.5 to 1mm.

C. *The Effect of the Ring on the Local Pressure Loss*

Orthogonal simulating how set h_2 and l_2 to make the local pressure loss be the biggest is done while h_2 and l_2 are set from 0.3 to 1.0mm by step 0.1mm. The result is as Fig .5.

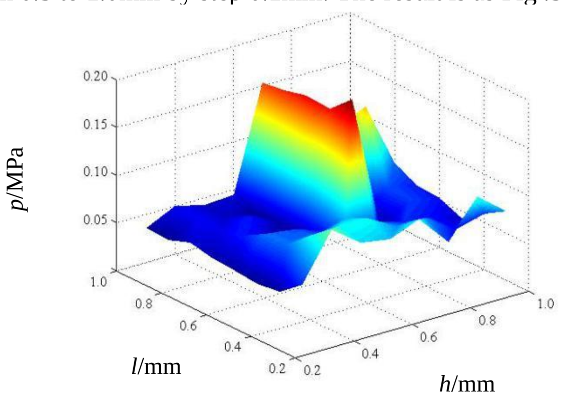


Figure 5. The pressure distribution when the width and depth of ring are changed

It is known from the result above that the local pressure loss is the biggest when h_2 is 0.5mm and l_2 is from 0.5~0.8mm about.

IV. THE INFLUENCE OF OIL RING'S PARAMETERS ON THE OIL CAVITY PRESSURE ANALYSIS

To prove the result above, the model of oil-film for hydrostatic guide-way Fig.1 is made as Fig.6: r_1=45mm, r_2=60mm, h_0=0.05mm, h=2mm, d=3mm,the length of inlet is 20mm. The pressure of the chamber is simulated while changing the ring's parameter such as its width, depth and the distance from the chamber. For doing this, some hypothesis should be given as follow:

①Oil is incompressible and steady flow;

②No relative slide between oil and solid;

③The pressure at outlet of oil film is zero.

④Ignore the inertia of oil and Thermal deformation of the work-table;

The condition for simulating is: the velocity of oil at the inlet is 100mm/s，the surface which oil contacts with work-table is Wall type, outlet is Opening type and the pressure is 0Pa, oil's density is 875kg/m3, its dynamic viscosity is 0.035Pa.s.

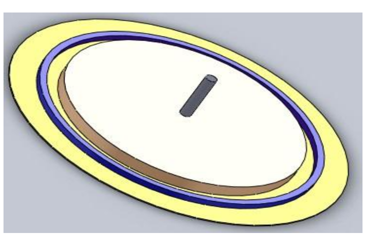


Figure 6. The model of fluid file with ring

A. *The Effect of the Position of the Ring on the Chamber Pressure*

The chamber's pressure is simulated while the distance from the ring to the chamber is changed as 1,3,⋯,13 mm but its width and depth are set as 0.5mm according to section 2. The results is shown as Fig .7 .

It is verified from the simulation above that the pressure is changed while changing the distance between the ring and the chamber. But the pressure is the highest when the distance is 5mm about. So the distance is taken as 5mm for following simulation.

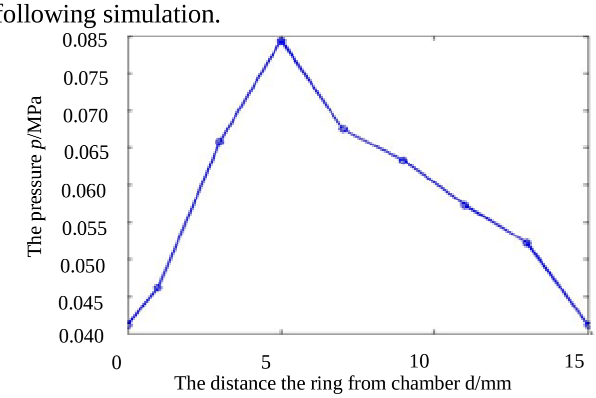


Figure 7. The curve for the effect of the ring's position on the chamber's pressure

B. *The effect of the ring's width on the chamber's pressure*

For analyzing the effect the ring's width on the chamber's pressure, the depth is set as 0.5mm, and the distance the ring from the chamber is set as 5mm according to section A. The chamber's pressure is simulated as Fig .8 when the width is changed from 0.1 to 1.0mm by step 0.1mm.

The bigger the width is, the higher the pressure is if it is smaller than 0.6mm about. But the bigger the width is the lower the pressure is when the width is bigger than 0.6mm,. The pressure is the highest while the width is from 0.3 to 0.6mm. The ring's width can be set 0.5mm while simulating following.

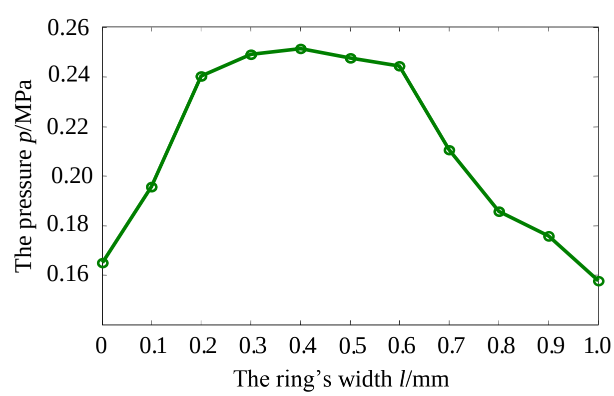


Figure 8. The curve for the effect of the ring's width on the chamber's pressure

C. The Effect of the Ring's Depth on the Chamber'S Pressure

For analyzing the effect the ring's depth on the chamber's pressure, the width is set as 0.5mm, and the distance is set as 5mm. The chamber's pressure is simulated as Fig .9 while the depth is set from 0.1 to 1.0mm by step 0.1mm.

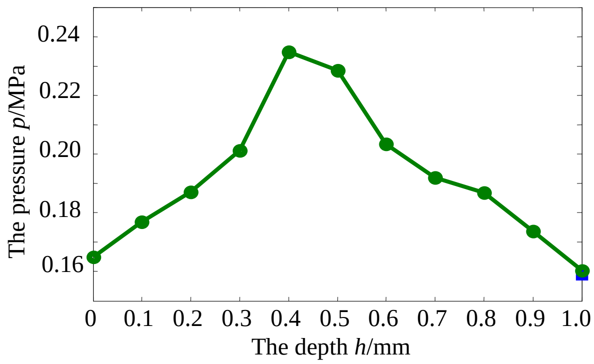


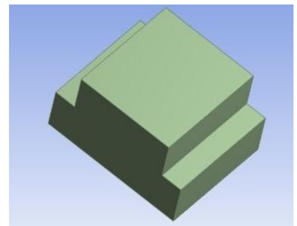
Figure 9. The curve for the effect of the ring's depth on the chamber's pressure

It is shown clearly that the changing trend of the chamber's pressure by the ring's depth is similar to that by its width, and the pressure is the biggest when the depth is 0.4mm~0.5mm.

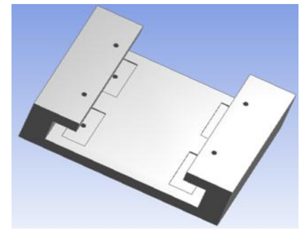
It is proved from above that the chamber's pressure can be increased when a ring is set in the oil seal edge of hydrostatic guide-way. In another words, hydrostatic resistance of hydrostatic guide-way is increased when a ring is set. So the design of a ring is the same important as that of the chamber for hydrostatic guide-way. The ring's width, depth and position should be chosen while designing the hydrostatic guide-way.

V. THE ANALYSIS OF HYDROSTATIC GUIDE-WAY STIFFNESS

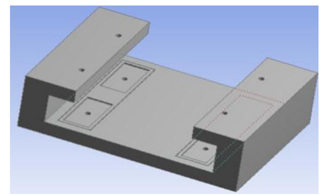
The closed hydrostatic guide-way fluid solid coupling simulation model is constructed in this paper to verify the simulation result above for hydrostatic guide-way. Four chambers were constructed on both up and down to reduce computation. The oil chamber was designed on guide-way as (a) and (b) in Fig.10. The lower chamber, which its length and width are 60mm and 30mm and the resistive edge width is 15mm and the distance between two chambers is 35mm, is for bearing only. The upper chamber's length and width are 70mm and 10mm and the resistive edge width is 10mm. The size of hydrostatic guide-way is: width 300mm, length 200mm, height 80mm. The fluid model is designed according to hydrostatic guide-way and slide block. The oil ring on the oil seal edge is 5mm far away from the oil chamber, its width and depth are 0.5mm. The model is shown as Fig .11. The condition for the fluid-soild model is shown as Fig .12.



(a) The slide block

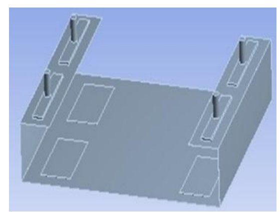


(b) hydrostatic guide-way without ring

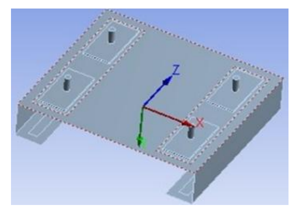


(c) hydrostatic guide-way with a ring

Figure 10. The solid model for closed hydrostatic guide-way



(a)The model for guide-way without a ring



(b)The model for guide-way with a ring

Figure 11. The oil film model for closed hydrostatic guide-way

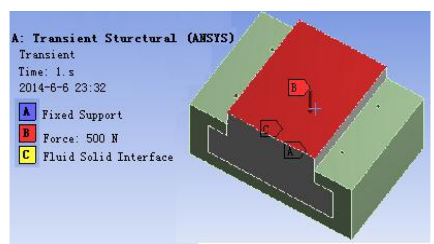
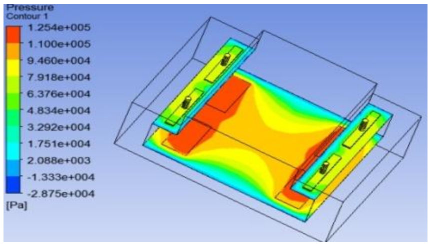


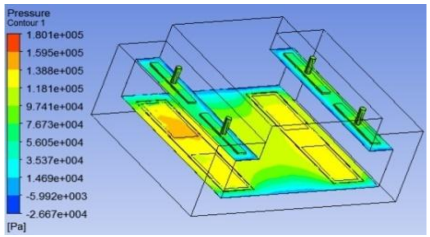
Figure 12. The edge condition of hydrostatic guide-way entity domain

For simulation the pressure of oil-chamber and displace of slider, the edge condition of hydrostatic guide-way is set as Fig .12. The chamber's pressure and the slider's displacement will be obtained when the force is loaded on the slider as Fig .13 and Fig .14. The bearing capacity and stiffness of hydrostatic guide-way with and without oil ring can be get while the force on slider is changed during the simulation as Fig .15 and 16.

It is proved from the simulation result that the bearing capacity and stiffness can be improved if a ring is set on the oil seal edge of hydrostatic guide-way. In the other hand, the liquid resistance can be increased when a ring is set on the oil seal edge of guide-way. The hydrostatic guide-way with high liquid resistance has better bearing capacity and stiffness.

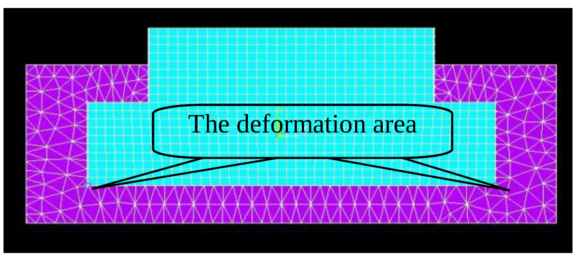


(a)The pressure distribution of guide-way without ring

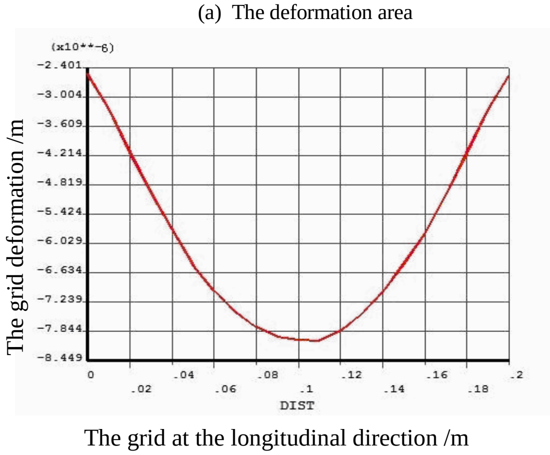


(b)The pressure distribution of Guide-way with a ring

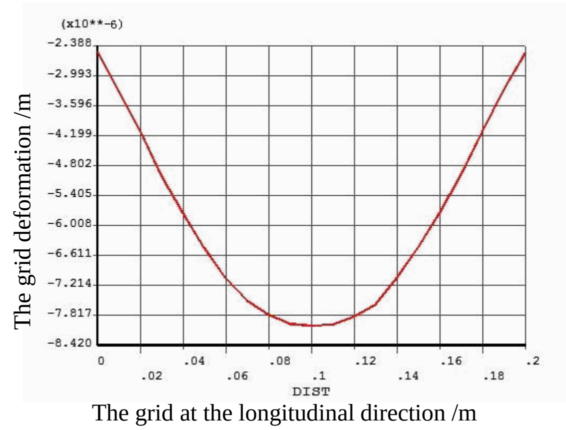
Figure 13. The oil-film pressure distribution for hydrostatic guide-way



(a) The deformation area



(b)This is for hydrostatic guide-way without ring



(c) This is for hydrostatic guide-way with a ring

Figure 14. The grid's deformation at the longitudinal direction

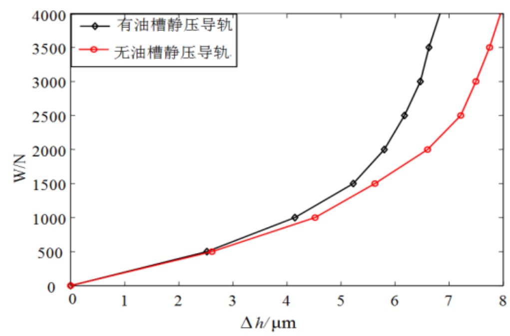


Figure 15. The curve for the relationship between oil-film thickness variation Δ h and force W

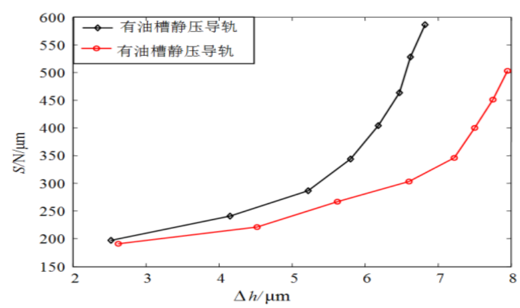


Figure 16. The curve for the relationship between thickness variation Δ h and stiffness S

VI. THE CONCLUSION

Hydrostatic guide-way is the most important supporting component for ultra-precision CNC machine tools, and its carrying capacity and stiffness are important performance parameters. In order to meet the requirements for ultra-precision CNC machine tool of ultra-precision, high-speed, a new type hydrostatic guide-way with high liquid resistance is put forward based on the generation mechanism of local pressure loss. The simulating has been done how the width, depth and position of the ring, which is on the oil seal edge of hydrostatic guide-way, effect on the oil chamber pressure. It is verified from the result that the chamber's pressure of hydrostatic guide-way can be enhanced significantly if the position, width and depth of the ring are appropriate. It is reasoned that the carrying capacity and stiffness of the hydrostatic guide-way are improved when a ring is set on its oil seal edge.

The conclusion can be got that the new type hydrostatic guide-way with a high liquid resistance has a better carrying capacity and stiffness because of a ring set on the oil seal edge if its position, width and depth are appropriate.

ACKNOWLEDGMENT

This research was financially supported by the Shaanxi Province Natural Science Foundation (No.014JM2-5067), haanxi Province Education Department key laboratory scientific research plan (No.13JS072).

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