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Flow field analysis and parameter optimization of main and measured nozzles of differential pressure type gas momentum instrument based on CFD

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Abstract. In honing on-line pneumatic measurement, the actual working conditions of honing have not been taken into account. While honing and online measurement of aerodynamic working environment is relatively small semi closed annular narrow space, various parameters will influence the movement characteristics of the measurement of gas, gas does not consider the previous online honing the actual working conditions of the dynamic measurement accuracy is hard to guarantee, does not meet the requirement of automatic processing of high precision. Through the combination of theoretical research and simulation experiment, through the study of honing, pneumatic measurement and aerodynamics, the characteristic equations of three working conditions under honing actual working conditions are obtained. Using fluid simulation software FLUENT to the actual working parameters of honing pneumatic measuring mechanism model is simulated, simulation results show that when the working temperature is less than the optimum value, to achieve amplification and linear range, complex parameter measurement, to meet the honing high dimensional accuracy and high shape precision and high automation requirements.

1. Introduction

With the development of automobile industry, higher requirements have been put forward for cylinder block and cylinder sleeve [1-3]. At present, high precision NC honing machine has been monopolized by foreign countries. Imported machine tools are expensive and become the bottleneck of promoting the development of the automotive industry. Therefore, it is imperative to develop domestic CNC honing machines. Among them, the research on the accuracy analysis of honing on-line pneumatic measurement technology has important practical significance.

Pneumatic measurement [4-7] is non-contact measurement, has good flexibility, non-destructive and stability, high sensitivity, strong anti-interference ability, easy realization of composite parameter measurement and self-cleaning function and other unique characteristics, to meet the honing high dimensional accuracy and high shape precision and high automation requirements.

With the further research of engine operation mechanism in engineering field, higher requirement of honing accuracy is put forward. The accuracy of honing machine determines the machining accuracy of



honing machine. At present, pneumatic measuring system is widely used in honing process. In the previous research on dynamic process of honing pneumatic measurement system is only for the static characteristics, dynamic characteristics of the few analysis on the actual conditions of honing gas dynamic characteristics analysis of measurement system is almost not involved, the design of pneumatic measuring parameters mainly adopts empirical estimation method of experiment. But to achieve the high precision of honing pneumatic measurement, it is not scientific to use static measurement instead of the actual working condition, and there is great error. Therefore, the dynamic analysis of pneumatic measurement and the actual conditions of the impact of measurement accuracy is essential. Therefore, this subject through the honing pneumatic measurement system dynamics theory and actual honing conditions of the measurement accuracy, to achieve high-precision honing pneumatic measurement, in order to meet the requirements of high-precision honing processing.

With the further research of engine operation mechanism in engineering field, higher requirement of honing accuracy is put forward. The accuracy of honing machine determines the machining accuracy of honing machine. At present, pneumatic measuring system is widely used in honing process. Lanzhou University of technology, Lanzhou Industry and Equipment Co. Ltd ZhangWanJun. ET, at researchers [15-21] have researched interpolation algorithms for NURBS curves honing pneumatic measurement system. Here has been attempts to change the feed rate in NURBS interpolation honing pneumatic measurement system.

From the domestic and international research status and related literature review, we can see that there are still some blind spots in the pneumatic measurement, especially for the pneumatic measurement of honing, and the key problems that need to be solved are as follows:

1) For pneumatic measurement, the domestic scholars have only studied the static measurement mechanism of pneumatic measurement, but the dynamic mechanism has not been studied. In real-time and on-line measurement, the measured object measurement system or one side will work in a particular state of motion, and pneumatic working medium - Measurement of compressed gas (due to the fluid characteristics) the dynamic characteristics and static characteristics are very different from the inevitable. Pneumatic dynamic mechanism is to achieve real-time online measurement of pneumatic measurement is essential, the past simple use of static measuring mechanism instead of dynamic mechanism of measurement approach has considerable error, cannot satisfy the demand of high accuracy.

2) In honing on-line pneumatic measurement, the actual working conditions (pressure change, While honing and online measurement of aerodynamic working environment is relatively small semi closed annular narrow space, various parameters will influence the movement characteristics of the measurement of gas, gas does not consider the previous online honing the actual working conditions of the dynamic measurement accuracy is hard to guarantee, does not meet the requirement of automatic processing of high precision.

This paper through theoretical research on aerodynamics and fluid mechanics, the establishment of honing pneumatic instrument model, and further optimize the working parameters of pneumatic instrument through computer simulation, dynamic debugging and measuring system on gas in theory and use give guidance to pneumatic better applied in machinery and other industries can measure.

In the previous research on dynamic process of honing pneumatic measurement system is only for the static characteristics, dynamic characteristics of the few analysis on the actual conditions of honing gas dynamic characteristics analysis of measurement system is almost not involved, the design of pneumatic measuring parameters mainly adopts empirical estimation method of experiment. But to achieve the high precision of honing pneumatic measurement, it is not scientific to use static measurement instead of the actual working condition, and there is great error. Therefore, the dynamic analysis of pneumatic measurement and the actual conditions of the impact of measurement accuracy is essential. This subject through the honing pneumatic measurement system dynamics theory and actual honing conditions of the measurement accuracy, to achieve high-precision honing pneumatic measurement, in order to meet the requirements of high-precision honing processing.

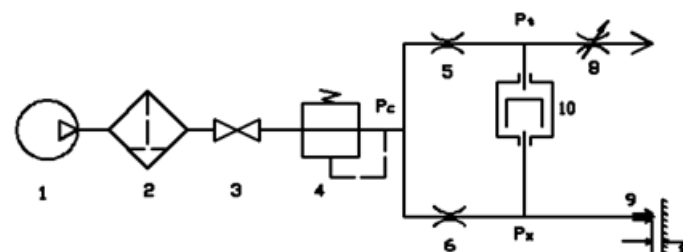
Pneumatic measurement [1] [2] is a non-contact measurement. It has high precision, small measuring force and self-cleaning function to the work piece under test. It is not affected by the surface material of the work piece. This method uses compressed air as the medium, the use of air in the pipe flow or pressure with the nozzle and the measured work piece gap between different change characteristics, size or the amount of displacement transformation flow changes or pressure signal, so as to achieve the measurement. However, due to the small size of the nozzle and the small size of the air jet, the selection of the parameters such as the main nozzle and the nozzle aperture in the aerodynamic measurement has been a difficult problem. Have a huge impact, and the main measuring nozzle aperture ratio and the measurement accuracy and sensitivity, so the analysis of differential pressure type gas flow path optimization, pneumatic measurement of the main measuring nozzle aperture parameters in pneumatic measurement is of great significance. By establishing the theoretical model parameters of pneumatic instrument design, analysis, flow field calculation and flow field prediction function flow using powerful CFD software can analyze and display the phenomenon of the flow field, in a relatively short period of time can predict object performance, and optimize various parameters.

2. The basic principle of differential pressure pneumatic measurement

2.1. Differential pressure gas path system

At present, two kinds of measuring methods are commonly used in the pneumatic on-line measuring system, backpressure and differential pressure. Simple pressure has its disadvantage of gas measurement, too high, or when the distance between the nozzle and the work piece is changed, once the air pressure fluctuations, work pressure will change, thus causing the measurement error, stability of [3] instrument failure. The differential pressure measurement can solve the problem and improve the performance of the meter. So the differential pressure measurement technique is used in this system.

The differential pressure pneumatic measuring principle diagram is shown in figure 1. The compressed air source through the filter 1 to 2, 3 and 4 after the intake valve pressure regulator P_c , with constant PC, divided into two flows. Through a throttle hole 6 through the nozzle flapper 9 into the atmosphere. The other path through a throttle hole 5 by regulating valve 8 into the atmosphere [1]. Obviously, measuring two back pressure pneumatic gas route (zero chamber and the measuring chamber, two) when measuring the backpressure gas path in the same ambient pressure and temperature, the external environment (pressure, temperature and humidity) to measure the impact of the minimum, high accuracy and stability of [4]. Two cavity pressure, according to fluid mechanics knowledge, through a cross-section of the subcritical state of the flow formula, force difference is: formula $\Delta P = P_t - P_x$; $\Delta P = f(S)$: P_t - Zero Zero cavity pressure; P_x - measuring chamber pressure. Generally adjustable flow valve in the measurement before adjusting the back pressure in the measurement process is the same, that is P_t , P_t is a constant. The measuring chamber pressure P_x changes with the change of measurement gap s . Using silicon piezoresistive differential pressure sensor 10 to detect ΔP , as the measured signal, amplified and output, you can measure the size of the parameter S . Schematic diagram of gas path of back pressure pneumatic meter, as shown in Fig. 1.



1. air source, 2. filter, 3. intake valve, 4. Regulator, 5, 6 orifice, 8. Control valve, 9. Nozzle baffle mechanism, 10. Silicon piezoresistive differential pressure sensor.

Figure 1. Schematic diagram of gas path of back pressure pneumatic meter.

3. Aerodynamic measurement model

The differential pressure pneumatic measuring principle is shown in figure 1. Compressed air from the gas source 1, after filter 2, intake valve 3 and pressure reducing valve 4, has a constant pressure of P_c , divided into two flows. Through a main nozzle 5 and measuring nozzle 6 into the atmosphere, high pressure input of the other way directly connected to the differential pressure sensor. Apparently, the gas path is the difference between the constant pressure input P_c and the measured chamber pressure P_x :

$$\Delta p = p_c - p_x \quad (1)$$

Where: p_c - constant pressure at the input; p_x - measuring chamber pressure.

The basic principle of pneumatic measurement is introduced with pneumatic back pressure pneumatic measuring system, and the schematic diagram is shown as follows:

The back-pressure indicator of p_x in different ways, its function is the variation of the pressure will be converted into Δp_x instructions (such as the original pointer, buoy, liquid column etc.) the amount of the mobile ΔL .

The back pressure type pneumatic meter is composed of at least two conversion links (or amplification links).

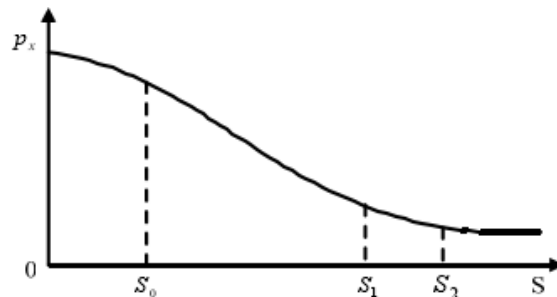
$$\Delta S \rightarrow \Delta p_x \rightarrow \Delta L \quad (2)$$

Among them, the change of ΔS is to measure the gap, $\Delta S \rightarrow \Delta p_x$ is called pneumatic converter, the P_x and the L amplification step instructions. The ratio of back pressure type pneumatic momentum instrument $\Delta p_x \rightarrow \Delta L$ is also determined by the transfer function of these two links, that means:

$$K = \frac{\Delta L}{\Delta S} = \frac{\Delta L}{\Delta p_x} \frac{\Delta p_x}{\Delta S} \quad (3)$$

The $\frac{\Delta p_x}{\Delta S}$ is called the conversion ratio of the pneumatic system, and $\frac{\Delta L}{\Delta p_x}$ is called the indicating conversion ratio. Some of the back pressure gas momentum instrument, and its amplification instructions link is also composed of a number of links, but all back pressure type pneumatic momentum instrument, its pneumatic change link working principle is the same.

When the measuring head is a nozzle baffle, the back pressure and the clearance S of the nozzle baffle are in one-to-one correspondence function relationship. The magnitude of the measured parameter S can be obtained as long as the back pressure value is read from the pressure indicator section 6. Between the pressure and the measurement of the gas chamber pressure nozzle flapper gap S function: $p_x = f(S)$ is shown in Fig.2.



0- S_0 : viscous part; S_0 - S_1 : linear part; S_1 - S_2 : transition part; after S_2 : horizontal part

Figure 2. Back pressure clearance curve (characteristic curve).

4. Characteristic equation of baffle

The characteristic equations of the plane baffle measurement system under four operating conditions are [13]:

Condition I:

$$P_x = P_c - \frac{P_c \left[\left(\frac{P_o}{P_c} \right)^{\frac{2}{n}} - \left(\frac{P_o}{P_c} \right)^{\frac{n+1}{n}} \right] \left(\frac{c_2 d}{c_1 \frac{d_1^2}{4}} \right)^2 S'^2}{\frac{n-1}{n} + \left[\frac{2n-2}{n} \left(\frac{P_o}{P_c} \right)^{\frac{2}{n}} - \frac{n-1}{n} \left(\frac{P_o}{P_c} \right)^{\frac{n+1}{n}} \right] \left(\frac{c_2 d}{c_1 \frac{d_1^2}{4}} \right)^2 S'^2} \quad (4)$$

Condition II:

$$P_x = \left[\frac{1}{2} P_0^{\frac{n-1}{n}} + \frac{1}{2} \left(P_0^{\frac{2n-2}{n}} + 4 P_0^{\frac{2}{n}} \frac{B^2 P_c^2}{A^2 S'^2} \right)^{\frac{1}{2}} \right]^{\frac{n}{n-1}} \quad (5)$$

Condition III:

$$P_x = P_c \left[0.5 + 0.5 \left(1 + 4 \frac{A^2}{B_1^2} S'^2 \right)^{0.5} \right]^{\frac{n}{1-n}} \quad (6)$$

Where, S' is the measuring clearance. C_1 - The flow coefficient at the orifice (main nozzle); d_1 - orifice diameter; P_c - work pressure (absolute pressure); P_x - back pressure (absolute pressure); n - the constant entropy index, for air; $\gamma_c - p_c$ under the severe gas.

Working area diagram of air momentum instrument, as shown in Fig. 3. By comparing with the equation of curved baffle measurement system characteristics, we can draw in the measuring chamber pressure p_x and other parameters of the nozzle under the same measuring clearance error measuring gap curved baffle and plane baffle is $\frac{d^2}{8D}$, the measurement accuracy is calculated according to the curved baffle characteristic equation characteristic equation of $\frac{d^2}{8D}$ is higher than the plane baffle.

The lines A, B and C intersect into four zones, i. e., II, III and IV respectively, which are the four conditions of back pressure meter, corresponding to the four working conditions listed in table 3.1.

The influence of the characteristic equation of the curved baffle and the characteristic equation of the baffle plate on the measurement accuracy is analyzed and compared. It is shown that the measurement accuracy of the characteristic equation of the curved baffle is higher than that of the planar baffle, and the accuracy is $\frac{d^2}{8D}$. When the honing accuracy is m 1 m and $D < 125d^2$, the influence of the diameter of the curved baffle on the measurement accuracy must be considered. The characteristic equation of the baffle cannot be used to study the characteristic equation of the curved baffle.

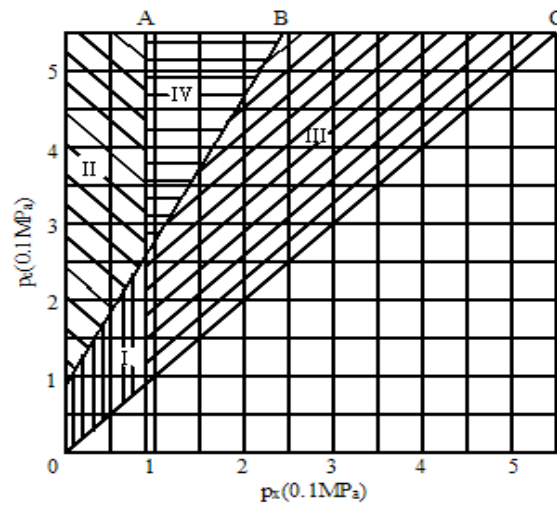


Figure 3. Working area diagram of air momentum instrument.

Through simulation experiments, we obtained the pressure of back pressure of gas chamber under different clearance of nozzle baffle p_x . Entrance pressure constant is 0.2MPa (g), $p_x - S$ function as the back pressure condition into the value of simulation and under the same conditions the value of the $p_x - S$ curve were drawn from 0 different gap corresponding to the start value, as shown in Fig.4.

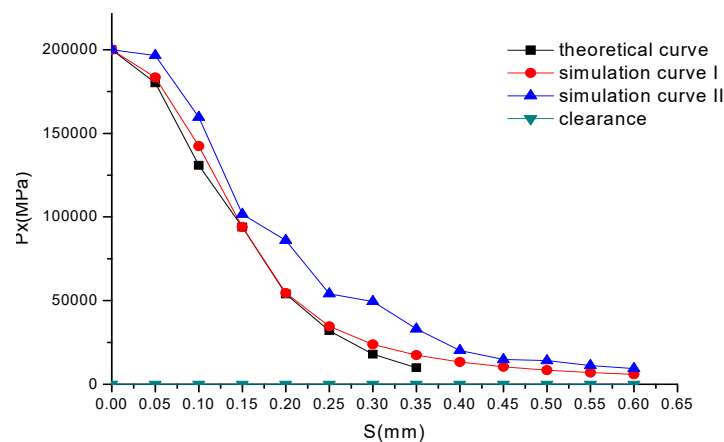


Figure 4. Comparison of theory and simulation

As can be seen from Fig.4, the theoretical curve and the simulation curve are similar in shape. They are composed of four sections, namely, the viscous part, the straight line part, the transition part and the horizontal part, and the slope is approximately the same.

5. Analysis of honing fluid flow field based on FLUENT

Compared with the back pressure type gas path, the advantages of differential pressure type gas path is to reduce the measurement error caused by the output pressure relief valve P_c changes, so the differential pressure type pneumatic measuring instrument, measuring the main nozzle as the research object were emphatically analyzed. According to the requirements of the project, the assembly diagram of the double feed grinding head of the river and the pneumatic transformation principle of differential pressure pneumatic measurement are drawn. The plane sketch map of the pneumatic transformation section of the differential pressure pneumatic instrument is drawn. In order to facilitate the research, the

main nozzle and the measuring nozzle are built in the same model. Compared with the back pressure type gas path, as shown in Fig.5.

Fig. 5 is the pressure nephogram of the air path. From the static pressure diagram, it can be seen that the gas pressure distribution in each part is very uniform. From the dynamic pressure diagram, it can be seen that the pressure of the gas varies very sharply at the throttle orifice and the nozzle baffle. The pressure in the pressure chamber and the back pressure chamber is relatively stable.

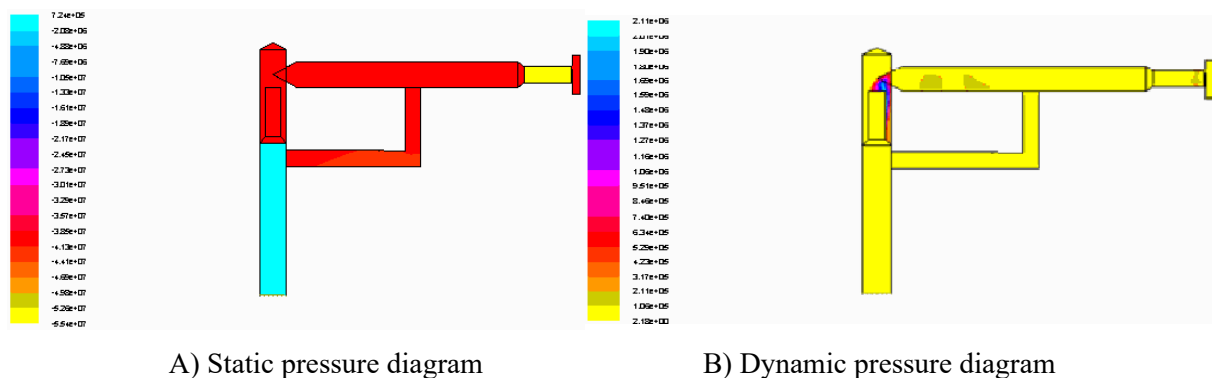


Figure 5. Pressure nephogram

6. Solution calculation and analysis

Using FLUENT for simulation solution, the first step is to initialize the flow field. Initialization means giving the initial values of each flow parameter so that the iterative computation can have a starting point. Initial flow field in two ways, one is the all cell initialization of the field with the same value of field variables, the other is a flow variable selection in selected cell regions in the coverage of a value or function [12-14].

After doing initialization work, the simulation iterative calculation [22-29] can be carried out, and the monitoring residual error of the solution process is also set up. The convergence condition of this paper is as follows: the residual energy is less than 10^{-6} , and the convergence requirement is achieved. The exit velocity monitoring, shown in Fig. 6, Fig.7 and Fig.8. Eventually tends to remain constant, further monitoring the good convergence performance of the iterative computations.

After calculation, you can see two results of data and graphics. Figure 4 is the speed of cloud of gas path, in the figure can be seen in the velocity of fluid in each position, in the entrance orifice and nozzle baffle, flow rate of gas is maximum, supersonic phenomenon occurs even in local small range. At the same time, the airflow emitted by the nozzle is blocked by the baffle plate, and the speed is lowered instantly, and the throttling of gas is formed at the outlet.

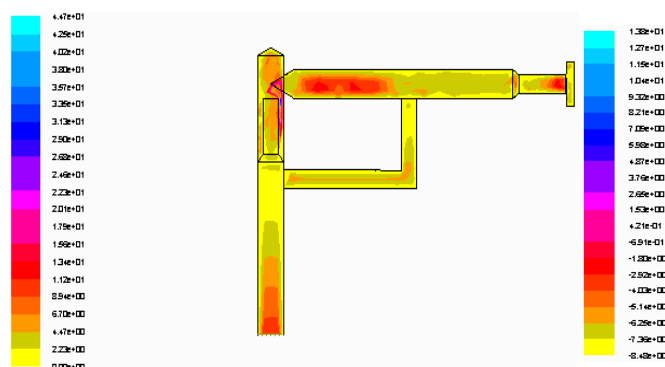


Figure 6. Static speed diagram.

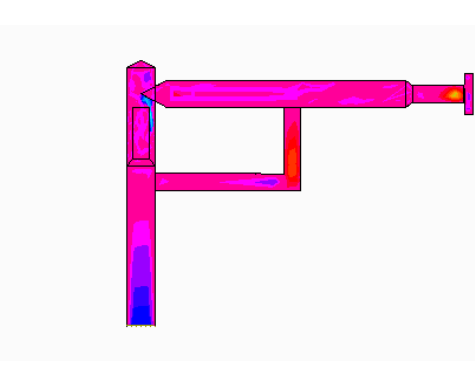


Figure 7. Tangential velocity diagram.



Figure 8. Measuring the total pressure of the nozzle

7. Experiment simulation and analysis

In our laboratory, the main nozzle, measuring nozzle experimental data diagram, Simulation, curve, of, NC, honing, machine diagram, as shown in Fig.9, the nozzle and measuring nozzle experimental data are shown in Fig.10.

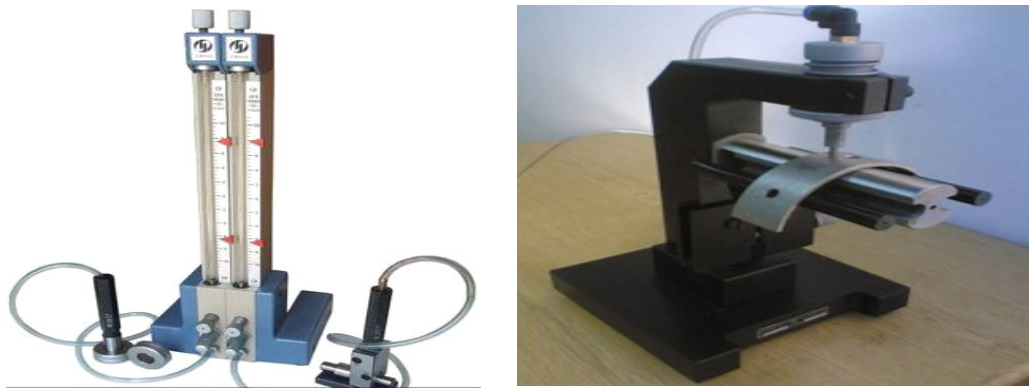


Figure 9. Simulation curve of NC honing machine.

The inlet pressure is 0.2MPa, and the pressure values under different working conditions are listed in Tab.1.

Table 1. Comparison of model pressure (p_x/p_a) at three operating temperatures

| Clearance S/mm | Kinematic viscosity of honing fluid ($cst(40^{\circ}C)$) | | |
|----------------|--|--------|--------|
| | 3 | 5 | 8 |
| 0 | 19999 | 199999 | 199998 |
| 0.05 | 180101 | 183475 | 196591 |
| 0.1 | 130902 | 142402 | 186742 |
| 0.15 | 94004 | 94018 | 171587 |
| 0.2 | 54002 | 54552 | 156011 |
| 0.25 | 32082 | 34670 | 134078 |
| 0.3 | 17948 | 23882 | 129490 |
| 0.35 | 9902 | 17462 | 93049 |
| 0.4 | | 13338 | 70186 |
| 0.45 | | 10502 | 54880 |
| 0.5 | | 8496 | 44122 |
| 0.55 | | 7014 | 36263 |
| 0.6 | | 5892 | 30342 |

Draw the values shown in Tab.1 to the corresponding curves, as shown in Fig.10.

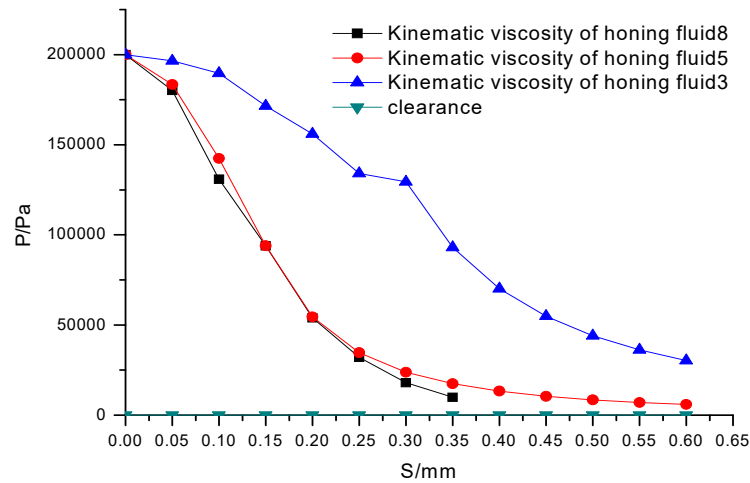


Figure 10. Comparison of characteristic curves of the model under three operating conditions.

As you can see from Fig. 8 that we can draw the following conclusions:

1). With the increase of honing fluid viscosity, the amplification (slope of the straight line) of the pneumatic conversion section decreases;

2). As the honing liquid viscosity increases, the viscosity of the curve increases with the increase;

3). As the honing fluid viscosity increases, the linear part of the curve increases with the increase.

These indicate that the honing liquid viscosity increases required to reduce the initial clearance measurement of pneumatic measuring instrument and the maximum measuring gap, fixed on the measuring device parameters, the viscosity of the oil film is not blowing through or not completely blown open, should avoid such a situation, a kinematic viscosity control in liquid honing the following.

Table 2. Comparison of model pressure (p_x/p_a) at three operating temperatures

| Clearance S/mm | Working condition temperature ($^{\circ}\text{C}$) | | |
|----------------|--|--------|--------|
| | 15 | 25 | 45 |
| 0 | 199999 | 199999 | 199999 |
| 0.05 | 195671 | 183475 | 196524 |
| 0.1 | 183352 | 142476 | 189675 |
| 0.15 | 164787 | 94016 | 185988 |
| 0.2 | 145014 | 54554 | 180012 |
| 0.25 | 148812 | 34671 | 176436 |
| 0.3 | 100428 | 23882 | 174673 |
| 0.35 | 72460 | 17468 | 173437 |
| 0.4 | 54829 | 13323 | 170309 |
| 0.45 | 42960 | 10504 | 168943 |
| 0.5 | 34616 | 8496 | 163560 |
| 0.55 | 28475 | 7012 | 162645 |
| 0.6 | 23842 | 5897 | 160783 |

Draw the values shown in Tab.2 to the corresponding $p_x - S$ curve, as shown in Fig.11.

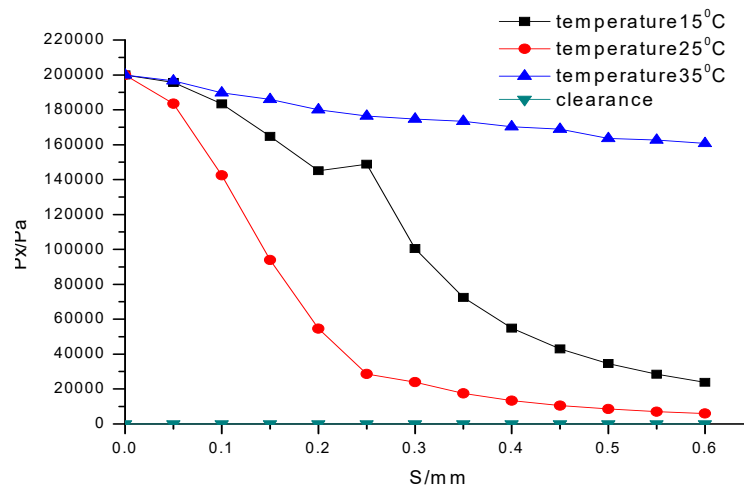


Figure 11. Comparison of characteristic curves of the model under three operating conditions.

As you can see from Fig.11, the temperature has a great influence on the characteristic curve. With the increase of working condition temperature:

- 1). Amplification (slope of the straight line) of the pneumatic conversion section decreases;
- 2). Viscosity of the curve will increase to a certain extent.

The linear part in the middle of the 3. Curve is also considerably reduced.

This shows that the increase in temperature conditions of honing pneumatic measurement have a negative impact, will make the measurement of the magnification is reduced, the linear part of the available decreases and the measurement accuracy is reduced, so the working temperature should be strictly controlled. Operating conditions shall not exceed the temperature.

8. Summary

This paper establishes a theoretical model parameters of pneumatic instrument design of differential pressure, flow field analysis using CFD software, the curve of differential pressure ΔP with flapper gap S change background structure parameters and the optimization of the main nozzle, test, provide a reliable reference for designers. These are important to design and study differential pressure pneumatic meter.

Acknowledgements

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