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SIMULATION ANALYSIS ON THERMAL ASSEMBLING OF VALVE ROD AND PLUNGER

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ABSTRACT

Simulation had been carried out upon the process of thermal assembling of valve rod and plunger in this paper by employing the software ANSYS WORKBENCH. First, it could be confirmed that the expansion magnitude of inner hole diameter of 0.3mm valve rod meets the assembling requirements, in accordance with the expansion condition after being heated of valve rod assembling section under simulation based on the assembling temperature calculated in theory and the deformation analysis upon valve rod after heating. Then, analysis of stress and strain upon assembly body after cooling had been conducted in the process of installing simulation plunger into valve rod and valve rod shrinking with cold to hold tightly plunger rod, which had provided theoretical analysis for thermal assembling of valve rod and plunger.

Key Words: Thermal Assembling, Simulation, Strain, Stress.

I. Introduction

The throttle, as an important part of exit end throttling system of gas Christmas tree, has played a crucial role in gas production at operation area and production safety. The valve spool, composed by valve rod and cage, serves as the core of throttle. Hence, once valve spool is out of operation, the throttle would be ineffective and the valve spool should be replaced. To date most of the oil fields in China have employed imported throttle massively, which is not in high cost but with long delivering cycle and has exerted adverse impact upon the production and management of oil field to some extent. Hence, the localization of throttle must be enforced, and analyzing the various technological indexes and technologies of processing and production of throttle has been the primary goal of localization. At the present stage, the study upon the throttle at home and abroad has mainly focused on the composition proportion of runner design of valve body, erosion resistance design of valve spool, tungsten carbide plunger, rather than the assembly technique of valve rod. With the increasing application amount of homemade throttle, the demand for valve rod has increased gradually. Moreover, in the process of assembling valve rod, the thermal assembling of plunger and valve rod has played an important role. The deformation condition of valve rod after being heated and the strain and stress status of assembly body after assembling and cooling had been analyzed based on simulating the thermal assembling of valve rod and plunger by applying finite element software, which has provided theoretical foundation for flow path of thermal assembling of valve rod.

II. The Assembling Theory of Valve Rod and Plunger

The valve rod and plunger has been adopted interference fit, whose assembling method could be divided into cold assembling and thermal assembling. In general, direct plunging method could be employed when it comes to small-size part, which is cold assembling; while the method of heating fenestrated part could be applied when it comes to large-scale equipment, such as assembling vane wheel and its rotating principal axis, which is thermal assembling. In addition. The expansion magnitude of diameter of hole after being heated has to be larger than the sum of interference magnitude and demanded assembling clearance magnitude[1, 2].

The object of study in this paper had been employed thermal assembling method, although it was small-size part. In addition, it has to work under severe environment, such as under high pressure and multi-phase flow, and to be with biggish interference magnitude, together with that carbide material was fragile and hard, therefore cold assembling could result into internal face of valve rod being struck and cut by plunger rod and part being broken. As a result, thermal assembling had been employed.

The thermal assembling process of valve rod and plunger is that installing a plunger into valve rod, whose inner hole diameter is larger than diameter of the plunger rod. Vertical assembly had been employed in the process of assembling, which was that the valve rod should be fixed at certain place vertically first, then assembling end should be heated in high frequency, then plunger should be installed that had held the fenestrated end face of valve rod with the step surface of plunger, in the end, it should be cooled under environment temperature. As the temperature goes down, the valve rod would be cooled, therefore it shrinks at radial direction and axial direction. With its inner hole holding tightly on to the plunger rod, their thermal assembling had finished. The so-called high-frequency heating means that put the metal to be heated into induction coil with high-frequency current and then the metal would be heated by eddy current heating effect created by changing electromagnetic field.

III. Designating Heating Temperature

In the process of thermal assembling, 316l stainless steel valve rod serves as heating object, WC plunger serves as part to be installed, hold diameter of valve rod shall be smaller than the diameter of plunger, the interference magnitude shall be 0.18 mm, the combination diameter shall be 22 mm, the min. assembling clearance in the process of thermal assembling shall be 0.12

mm, and the environment temperature is 22℃. The heating temperature could be denoted as the following formula:

$$t_n = \frac{e_{ot}}{\alpha d_f} + t$$

In the formula,

t_n— heating temperature, ℃

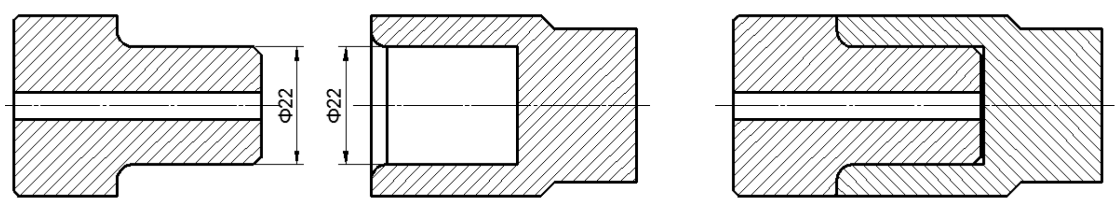
e_{ot}—thermal expansion magnitude of inner diameter of heating work-piece(equal to the sum of interference magnitude and the min. Clearance in the process of thermal assembling),mm

α— coefficient of thermal expansion of material, 1/℃

d_f—Combination Diameter, mm

t—environment temperature,℃

In accordance with engineering experience and limitation of heating equipment, coefficient of thermal expansion of stainless steel material 316l is 1.68e^{-5}/℃, and the heating temperature is $t_n = \frac{0.12+0.18}{22\times1.68\times10^{-5}} + 22 = 834℃$. In addition, the above formula is generalized formula of hole and shaft type thermal assembling and has not taking actual part shape and heating mode into consideration, therefore the heating temperature could only serve as reference temperature in the process of assembling in reality. The assembling condition is as shown in figure 1:



(1) Plunger(2) Valve Rod(3) Installing Plane Graph

Fig.1 Installing Plane Graph

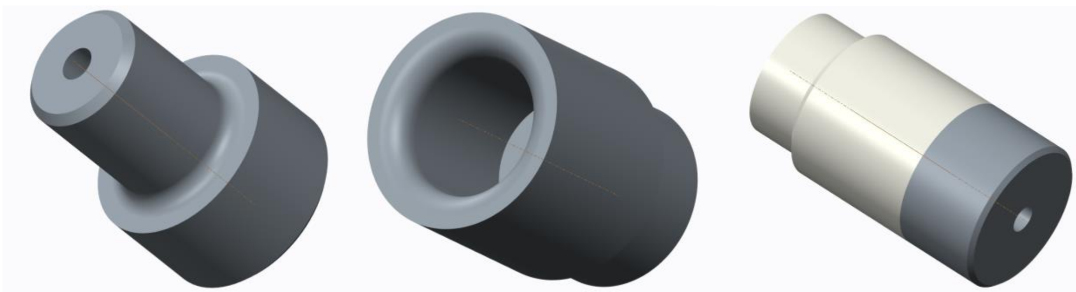
IV. Simulation Analysis of Finite Element

4.1 Calculation method and process of finite element

The thermal assembling flow path of valve rod and plunger had been simulated in this paper by employing the static analysis module of ANSYS WORKBENCH, by means of load of combination temperature, by regarding actual assembling process as sequence. First, calculating temperature filed, working as initial field, had been added to the model; after calculating the deformation of valve rod after being heated, it has to be checked whether or not that deformation meets assembling requirements; then, in the process of simulating plunger installing into valve rod, there moments have to be selected in order to record the strain process of valve rod; finally, in the process of simulating cooling assembly body, it strain distribution and stress distribution have to be calculated after it has cooled down.

4.2Build model of valve rod and plunger

The simulation object in this paper is derived from actual product. The whole body of valve rod is no need to be heated, but the region that assembling plunger, because the valve rod is long and thin and assembly only happens to its big end. Hence, when it comes to modeling, simplification treatment could be carried upon valve rod, and the simulation model could be 1/4 of the simplified model of assembling body. The model is as shown in figure 2:



(1)plunger model (2)simplified model of valve rod(3) model of assembling body

Fig.2 simulation model

4.3 Simulation analysis of deformation of valve rod after being heated

The analytic target, material of valve rod, is 316l stainless steel, the material of plunger is tungsten carbide, and the interference design vale of valve rod and plunger in model is 0.18mm. Because the material of plunger is tungsten carbide, whose surface is fragile and hard, the mounting clearance shall be no less than 0.12mm, in order to prevent collision between its surface and hole wall of valve rod in the process of assembling and result into break the surface of plunger rod. Hence, the min. Deformation value of inner hole before assembling shall be 0.18+0.12=0.3mm. The analysis upon valve rod under thermal load is as follows. Analytic procedure: a cylindrical-coordinate system shall be build fist based on default coordinates, two symmetry constraints and friction-free support on small end-face shall be exerted upon model[3], 834℃ thermal load shall be exerted upon valve rod model in accordance with calculating temperature, and thermal deformation of valve rod shall be calculated in accordance with the added temperature load.

The key point in studying thermal deformation is the connection between the expansion magnitude of inner hole of valve rod and design value 0.3mm. Based on the newly-built cylindrical-coordinate system, the expansion magnitude at radial direction of heating entirety could check by choosing X direction. As shown in figure 3, the expansion magnitude at radial direction of valve rod had increased in proper order from the inside out, and the max. value appeared on external wall surface of valve rod, which was 0.23mm. That is to say, by heating to 834°C, the diameter of external wall surface of valve rod had increased by 0.46mm. However, the min. value appeared on axes of valve rod. The expansion magnitude at radial direction of wall surface of inner hole of valve rod was 0.149mm. That is to say, by heating to 834°C, the inner hole diameter of valve rod had increased by 0.298mm. Hence, as for the demanded 0.3mm, the simulation result and the calculating result were having something in common, and plunger was available to be assembled into valve rod.

Moreover, the simulation result had played little in actual assemblyat axial direction, because the deformation at this direction of valve rod had close relation with the length of simulation model and restricted location at axial direction. The deformation at axial direction was as shown in figure 4.

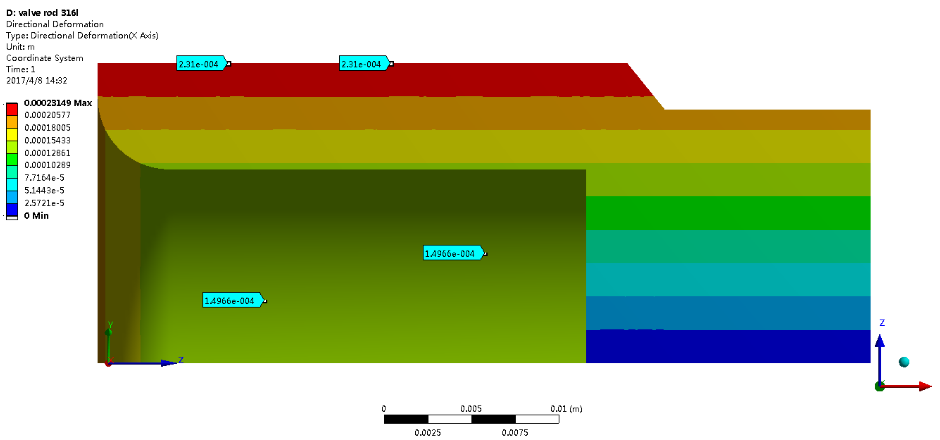


Fig.3 Deformation Graph at Radial Direction after Valve Rod being Heated

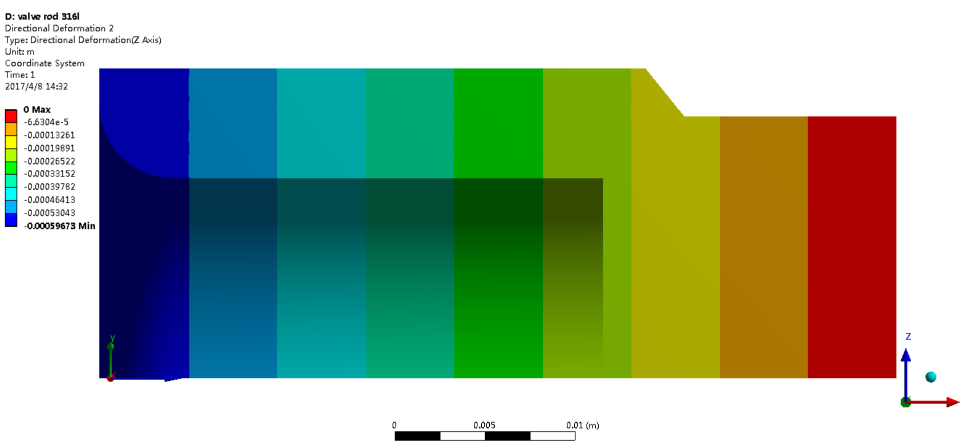


Fig.4 Deformation Graph at Axial Direction after Valve Rod being Heated

4.4 Simulation analysis of stress and strain of assembly body

Once valve rod has been heated up to designated temperature, plunger shall be installed instantly. The criterion of assembly is whether or not the fenestrated end of valve rod is matched with the step surface of plunger, which means that the two surfaces as shown in figure 1 are holding together. If they are holding together, the assembling is in right position; if not, the plunger rod must be stuck in certain position of inner hole of valve rod, therefore keep heating the valve rod until the plunger has moved downwards to assembly position. After finishing thermal assembling, the valve rod and plunger shall be placed under indoor temperature for cooling down. After cooling down, the there will be some small cracks on the two faying surfaces of valve rod and plunger, which is normal phenomenon.

4.4.1 Simulation analysis of stress of assembly body

The stress condition of assembly body after cooling down is as shown in figure 5. The stress magnitude of contact region between valve rod and plunger rod is from 189Mpa to 236Mpa, which has resulted into yield of contact region between inner wall surface of valve rod and plunger rod. From the direction of inner hole to external surface, the stress magnitude distribution of valve rod has come close to 140Mpa gradually. In this process, the plastic strain region has become less and less, while elastic strain region has become more and more. The max. Stress appears at the chamfer of plunger rod, which is resulted from stress concentration phenomenon. In the meantime, the stress distribution with biggish value appears at corresponding inner hole, because it is without any supports, whose max. Value is 425Mpa. In addition, it is elastic strain, when it comes to the material of plunger.

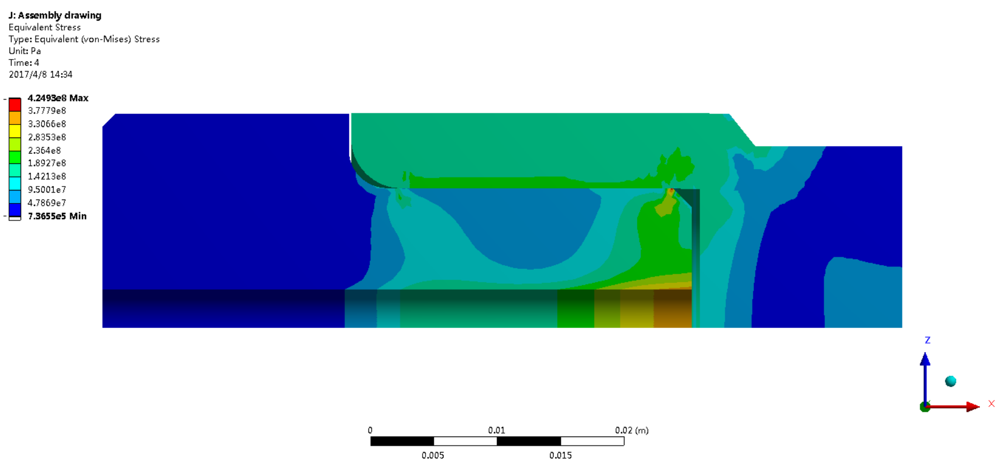


Fig.5 Equivalent Stress Graph of Assembly Body after being Cooled

4.4.2 Simulation analysis of strain of assembly body

In the process of cooling down the assembly body, the valve rod held tightly on to the plunger rod and was restricted by the plunger rod when it was shrinking, and the shrinkage deformation of its inner hole had reached to the degree when it was swelling and there was interference fit between certain deformation and plunger rod. When the valve rod was shrinking, the contact stress that exceeded the yield strength of 316l material appeared at the adjacent region of contact surface, because the wall surface of inner hole of valve rod was restricted by plunger rod. As shown in figure 5, the stress of contact surface was from between 189Mpa and 236Mpa, which has exceeded the 180Mpa yield strength of 316l, therefore plastic deformation occurred on the wall surface of inner hole of valve rod. In the process of simulating shrinkage, three time moments successively should be chosen on the plastic strain graph of valve rod, as shown in figure 6-8.

When the valve rod was shrinking at early stage, stress concentration occurred because two positions(chamfer of inner hole of valve rod and top of plunger rod) in figure 6 between the valve rod and plunger rod had abrupt change of contact section, which had led to plastic deformation upon the two positions. The max. plastic deformation occurred at the contact position between the valve rod and top of the plunger rod, whose value was 0.000345. As shown in figure 7, as the further shrinking of valve rod, its contact surface with plunger rod had become greater and greater, and the plastic deformation distribution enlarged from overall wall surface of inner hole to external wall of valve rod. The max. plastic deformation occurred at the same position, whose strain value had reached to 0.00167. The final plastic strain distribution graph of assembly body after cooling down to indoor temperature was as shown in figure 8. With the two assembled parts holding tightly, the distribution range of plastic strain had enlarged to the entire assembling end of valve rod, whose max. strain value was 0.02. Moreover, the plastic strain on wall surface of inner hole of valve rod was the most distinct, and there was large-scale of elastic strain at the same time. Hence, as for the valve rod after thermal assembling, there must be plastic deformation on contact surface with it and plunger axle. At that moment, the broken plunger could not be taken down from the valve rod for reuse, because interference value had failed to reach to the assembling requirement. As for the plunger material, tungsten carbide, it had experienced plastic deformation in the process of shrinking, because its yield strength is too strong that is much more stronger than the value of contact stress.

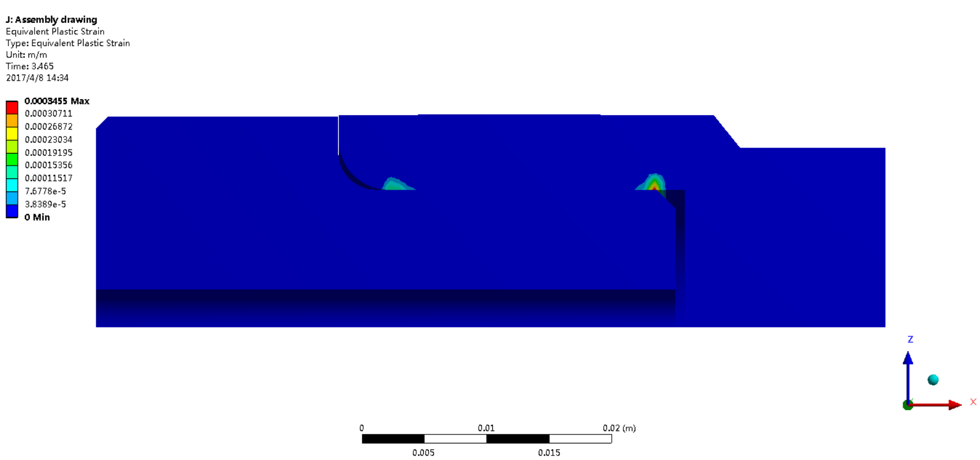


Fig.6 Plastic Strain Graph of Assembly Body in the First Moment

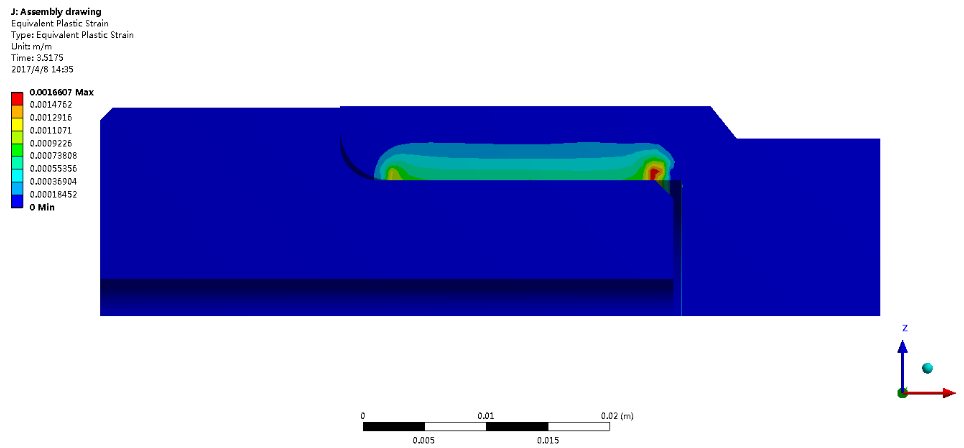


Fig.7 Plastic Strain Graph of Assembly Body in the Second Moment

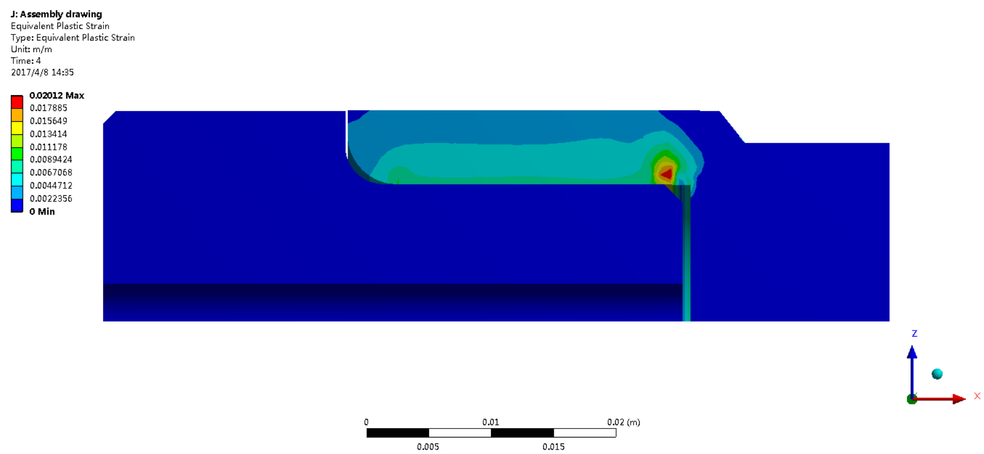


Fig.8 Plastic Strain Graph of Assembly Body in the Third Moment

After thermal assembling of assembly body had been finished, there were cracks with certain width on the stage surface of plunger and end face of valve rod, and that kind of width would exerted direct impact upon service life of valve rod. Under adverse working environment, if the crack of valve rod is too large, the exposed plunger rod would be eroded unceasingly by high-pressure multi-phase fluid and the sectional area of plunger rod would decrease. Together with impact shock, bearable bending moment and material property of tungsten carbide etc., the plunger rod would break and the function of throttle could fail. Hence, controlling width of crack effectively is with great significance.

We can find out reasons in the simulation figure effectively, by choosing two points in the figure 9, one of the point is on the contact surface between valve rod and plunger rod, which refers to the shrinking magnitude at radial direction of contact surface of valve rod; the other point is on the non-contact surface, which refers to the shrinking magnitude at radial direction of non-contact surface of valve rod. As shown in the figure, the deformation value of contact region at radial direction is $8.842e^{-5}$m, while the deformation value of non-contact region at radial direction is $2.7101e^{-5}$m, which means that the shrinking magnitude of non-contact surface is larger than that of contact surface. In this way, the deformation magnitude in the transition region between contact surface and non-contact surface is close to be the same and the shrinking magnitude of non-contact region decreases gradually, which produces a kind of thrust upon plunger rod and leads to out-shift of plunger and produce crack. Meanwhile, because the valve rod is in the stage of thermal expansion at the early stage of assembling, width of crack would enlarge further when the valve rod is shrinking at axial direction after the assembly body being cooled down.

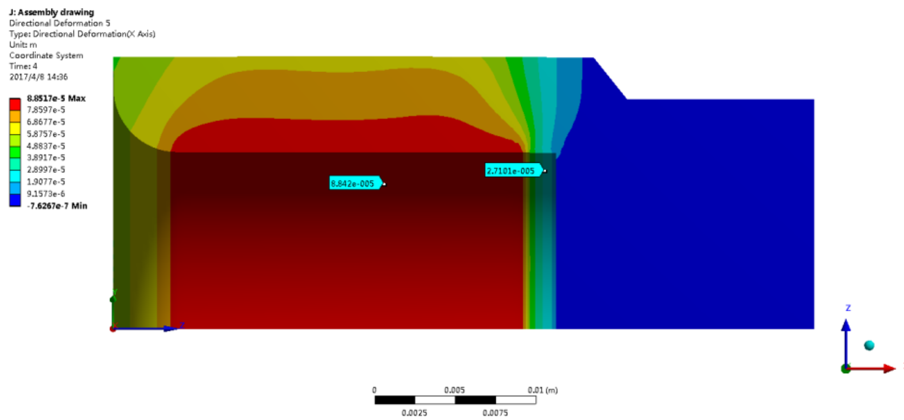


Fig.9 Deformation Graph of Valve Rod at Radial Direction after Assembly Body being Cooled

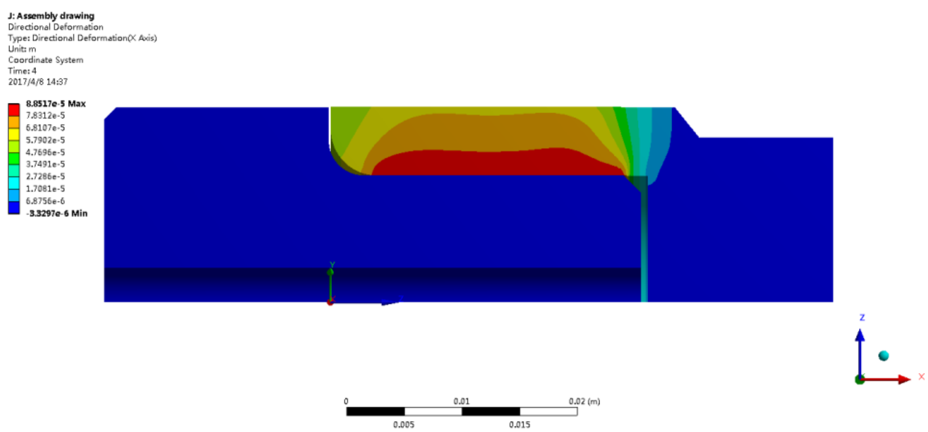


Fig.10 Deformation Graph of Assembly Body after being Cooled at Radial Direction

V. Conclusion

The heating temperature of valve rod that meets the requirements for assembling valve rod and plunger had been figured out in this paper by virtue of simulating the flow path of thermal assembling of valve rod and plunger. Moreover, simulation analysis upon deformation of valve rod after being heated had been carried out, which has provided theoretical foundation for thermal assembling of valve rod and plunger to some extent. Then, the strain and stress condition of assembly body had been assembled after being cooled, the reason for cracking on contact end face between valve rod and plunger had been analyzed, and it turned out that plastic deformation occurred at the contact region between inner hole of valve rod and plunger rod, and reloading new plunger again for re-using valve rod after thermal assembling had failed; other regions on valve rod were mixed with elastic deformation and plastic deformation, while plunger was only with elastic deformation.

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