

Simulation Study of AC Contactor Dynamic Contacts Contact Pressure Based on ADAMS

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ABSTRACT: A multi-body dynamics simulation model of CJ20-25 AC contactor was established with Pro/E (Pro/Engineer) in this paper. A coupling simulation with machine, electric, magnetic on the contactor has been achieved in this model. Dynamic parameters which were called use the secondary development technology of ADAMS. The dynamic contact pressure signal of an AC contactor was obtained with ADAMS's own simultaneous solution such as electromagnetic suction, kinematics and dynamics equations. The simulation results and actual measurement of contactor contact pressure signals are very similar. However, the complexity of the measured contacts vibration is greater than the simulation results because the actual working condition is more complex. This result provides a theoretical foundation to the dynamic contacts contact pressure test.

Keywords: AC contactor, coupling simulation, ADAMS, dynamic contacts contact pressure

1 INTRODUCTION

In recent years, the virtual prototype technology is widely applied in the field of low voltage apparatus modern design. Compared with traditional methods of physical prototype, the virtual prototype technology greatly shortens the product development cycle, reduces the product cost in creating design, test and evaluation.

At present, the researchers at home and abroad have done a lot of research on dynamic characteristics of core and coil and the dynamic process of AC contactor, and obtained lots of beneficial results. But most of them only studied the moving contact and moving core displacement and the velocity and electromagnetic force, however, they studied less in contact bounce during the contact collision. In document [1], the electromagnetic suction was calculated with simple suction formula of magnetic circuit and uniform magnetic field without taking into consideration of the friction influence. Though the contact bounce phenomenon was studied theoretically when the contactor closed, the error of this calculation method is great [2-4].

In this paper, a multi-body dynamics simulation model of AC contactor CJ20-25 was established with Pro/E (Pro/Engineer). A coupling simulation with machine, electric and magnetic on the contactor has been achieved in this model. Dynamic parameters which were called use the secondary development technology of ADAMS. The dynamic contact pressure signal of an AC contactor was obtained with ADAMS's own simultaneous solution such as electromagnetic suction, kinematics and dynamics equations. Then this paper can compare the simulation results with the measured results to study the relationship of the contactor contact bounce and the contact pressure.

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2 THREE-DIMENSIONAL ENTITY MODEL OF AC CONTACTOR

The 3D entity model was established based on AC contactor CJ20-25 sample. AC contactor CJ20-25 is a typical counterpunch type. Its electromagnetic mechanism includes dynamic core, static iron core, magnetic ring, coil, reaction and buffer spring-system. Actual use shows that the design of the electromagnetic mechanism is reasonable. It can significantly reduce the secondary vibration of contact and improve the life span.

Referred to the above results, this paper firstly analyzed the function and cooperative relationship of the contactor components based on the drawings and actual prototype of AC contactor CJ20-25, and established the assembly model of the AC contactor. Because the dynamic characteristics simulation of AC contactor electromagnetic mechanism is the main research aim, some structures which have no influence on the electromagnetic body movements can be ignored temporarily. Therefore, in the process of modeling, the model can be simplified with ignoring the parts which have no effects on the dynamic simulation, such as the insulating hood and base and the arcing cover, only doing virtual assembly of key parts. These parts include the dynamic and static iron core, moving and static contact, contact bridge, contact plate, spring supports, contact spring, flake spring, shading coil, and the main body bracket.

ADAMS itself has simple modeling capabilities, which is convenient to construct 3D model, but it can only establish some simple model structures. Because the model is complicated, this paper generally chooses professional CAD modeling software such as Pro/E, UG, etc.. Thus, it will be more convenient and quick. Here, this paper uses the Pro/E to do assembly model-

ing. In order to obtain the relative position of the parts and quality information, referred to the drawings, this research separates and measures the actual samples, and then creates models.

After creating the assembly model, this paper needs to lead the model from Pro/E into ADAMS and a large number of model parameters. There are many kinds of methods to lead model from Pro/E into ADAMS, each has advantages and disadvantages. Comprehensively considering the complexity of the contactor simulation model, this paper uses professional interface program Mech/Pro to make the software connect seamlessly, and realizes the high efficiency conversion. Then according to the actual movement of contactor, at the same time, considering contactor action of factors such as friction, heat, this paper adds the appropriate constraints, load and drive equation to the model in ADAMS, and thus, it can realize the dynamic simulation of the virtual prototype model on real significance. Because it is necessary to consider the impact which some variable parameters lead in the model, these parameters are defined as design variables, and the model is parameterized. The model is shown in Figure 1.

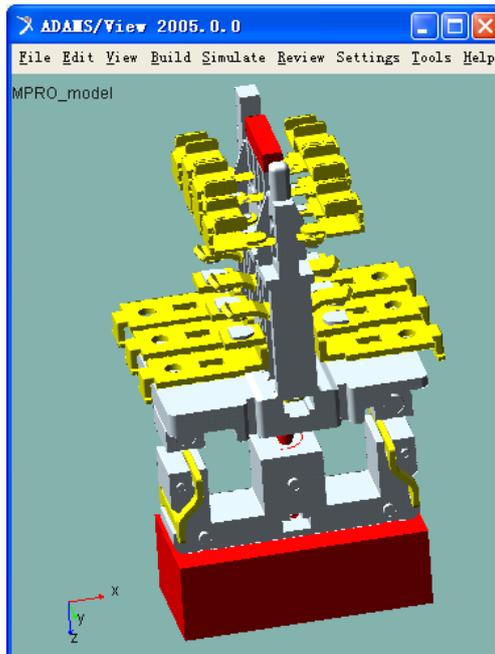


Figure 1. Contactor 3D entity model

In the process of adding constraint and simulating while adding constraints, various constraints can be examined if they are right or wrong. After simulation, the simulation results need to be tested in accordance to the actual movement. If the simulation results do not conform to the actual movement, this paper must modify and add the constraints again. During the pro-

cess of simulation, it is found that the constraint vice simulation of the three active contacts and the contact support with a universal vice is closer to the actual situation than with the translational vice. The main contact at both ends of the bridge type contact structure does not close at the same time, and this phenomenon can be simulated. The contact bounce is reflected to be more consistent with the actual situation.

The moving and static core, the moving and static contacts and the elastic components form the electromagnetic mechanism of counterpunch type. When analyzing the electromagnetic mechanism, it can be divided into 3 systems. First, the static core counterpunch subsystem. It includes static iron core, magnetic ring and so on. Second, the moving core contact support subsystems. They include dynamic core, buffer spring and contact support and so on. And the motionless system, namely the static iron core and the static contact support. In addition, there are normally open and closed auxiliary contacts which are used for output control signals.

The absorption process of the contactor contains electromagnetic transformation, heating and temperature rising, mechanical movement and so on. When the contactor closes, the circuit calculation can be obtained through a voltage balance equation. It uses the relation among coil excitation current, voltage, resistance and flux linkage. The movement calculation can be obtained by D'Alembert's equations of motion. It uses the moving and static core velocity, displacement and relationship between suction and counter force; the calculation of the magnetic field can be got by Maxwell's equations. The differential equations made up of these interconnected equations can be used to describe the dynamic process.

Contactor's closing process can be described in the following six stages: stage which is before the normally closed auxiliary contacts open; stage which is before the main contact and the normally open auxiliary contact do not close; stage which is before the normally closed auxiliary contact open, and the main contactor, normally open auxiliary contact close; the main contact and the auxiliary contact close, but the normally open core do not close stage; the main contact and normally open auxiliary contact close without bounce, but the normally open core do not close stage; the core close stage; after the core close without bounce stage.

Equation 1 is the third phase differential equations of the contactor movement. Because this research mainly studies the contactor contact pressure signal, this model considers the translational action core, contact support, the main contact, the translation and rotation of the normally open auxiliary contact, and ignores the contact support, movement and the rotation of the core. Since there is a strong spring pressure between the dynamic core and contacts stents, the relative displacement of them can be ignored. When contactor closes, the collision of the moving and static

contact is an inelastic collision, so the equivalent stiffness and the equivalent damping can be used to simulate the collision.

$$M\ddot{x}_1 + \sum_{i=1}^2 c_1^i \dot{x}_1 + \sum_{i=1}^2 k_1^i (x_1 + x_{01}) = F_x(i, x_1, x_2) - \sum_{j=1}^3 F_{3i}^j - \sum_{j=1}^2 F_{4i}^j$$

$$m_2 \ddot{x}_2 + \sum_{i=1}^2 c_2^i \dot{x}_2 + \sum_{i=1}^2 k_2^i (x_2 + x_{02}) = F_x(i, x_1, x_2)$$

$$m_3^j \ddot{x}_3^j + c_3^j \dot{x}_3^j + k_3^j (x_1 - s + x_3^j + x_{03}^j) = F_{3i}^j \quad (j=1,2,3)$$

$$m_4^j \ddot{x}_4^j + c_4^j \dot{x}_4^j + k_4^j (x_1 - s + x_4^j + x_{04}^j) = F_{4i}^j \quad (j=1,2)$$

$$J_3^j \ddot{\theta}_3^j + c_{\theta 3}^j \dot{\theta}_3^j + k_{\theta 3}^j \theta_3^j = M_{3i}^j \quad (j=1,2,3)$$

$$J_4^j \ddot{\theta}_4^j + c_{\theta 4}^j \dot{\theta}_4^j + k_{\theta 4}^j \theta_4^j = M_{4i}^j \quad (j=1,2)$$

$$F_{3i}^j = k_{3i}^j (x_3^j)^n + C_{3i}^j \dot{x}_3^j \quad (j=1,2,3)$$

$$M_{3i}^j = (F_{3i}^{j(1)} + F_{3i}^{j(2)}) \bullet r_3$$

$$F_{4i}^j = k_{4i}^j (x_4^j)^n + C_{4i}^j \dot{x}_4^j \quad (j=1,2,3)$$

$$M_{4i}^j = (F_{4i}^{j(1)} + F_{4i}^{j(2)}) \bullet r_4 \quad (1)$$

When calculating the suction of the contact mechanics model, the magnetic field and magnetic circuit method can be used to solve the magnetic circuit and voltage balance equation. When the air gap is large, the calculation error can be reduced through the finite element method, but the influence of the magnetic ring cannot be considered. When the air gap is small, the magnetic ring can be considered through the magnetic circuit method, and the calculation error is small. In this research, the two methods are combined. When the air gap is great, the method of "field" is used to analyze the model; when the air gap is small, the method of the "circuit" is used to calculate.

3 DESIGN FLOW OF ADAMS

For complex multi-body model with multiple degrees of freedom, the strong points of ADAMS in solving multi-body dynamics problem can be seen, and the dynamic visual simulation of AC contactor operating mechanism can be realized. The design flow of ADAMS includes the following five aspects: the model creation; the test and verification of the model; the refinement and iteration of the model; the optimization design and the interface customization.

4 MOVEMENT SIMULATION

There is no corresponding electromagnetic suction in ADAMS, and the essence of which is applying a load. The load of the equation is calculated by the ANSYS static data interpolation. ADAMS itself can form kinetic equations according to the constraints, automatic load and drive added previously. Therefore, just a voltage equation is needed in the model as shown in equation 2:

$$\frac{d\psi(i, \delta)}{dt} = u(t) - i(t)R \quad (2)$$

The electromagnetic suction calculation is divided in two stages: Big Air Gap and Small Air Gap stage. Where, Big Air Gap refers to the air gap which is greater than 1.5 mm, while Small Air Gap refers to the air gap which is less than 1.5 mm. Different calculation methods will be performed in two different stages to calculate the electromagnetic suction. When the moving core air gap is a Big Air Gap, a two-dimensional table $\psi(i, \delta)$ will be added in ADAMS. Where $\psi(i, \delta)$ can be obtained by binary interpolation of current i and air gap δ . The suction $F_x(i, \delta)$ can be obtained by binary interpolation of current i and air gap δ as well. The smaller the air gap is, the more obvious the role of the shading coil is. So the influence of the shading coil to suction needs to be considered.

After the parameters are set, select the CONTACT option in the display options, and the contactor contact pressure signal can be observed there. The simulation results are shown in Figure 2.

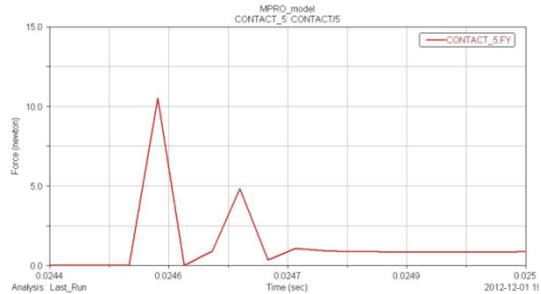


Figure 2. Contactor contact pressure simulation results

From the picture mentioned earlier, the simulation of the contact pressure waveform has two obvious bounces. The interval between the two bounces is about 1.5 ms. The amplitude of the first bounce is greater, and it's about 10 N. While the second bounce which is reduced by half is only about 5 N. The contact bounce is not damping exponentially, but slightly faster.

5 TEST OF THE CONTACTOR CONTACT PRESSURE

5.1 General scheme

Contact pressure is an important contact parameter, which has direct influence on the performance of electric apparatus. Electromagnetic relay and contactor are key elements in automatic control system. Contact pressure of Contacts must be sufficient when they close to ensure good contact [5]. Taking AC contactor for example, if the contacts' final pressure is great, the contacts will be welded by the electric arc due to the bounce. If the contacts' initial pressure is too small, the contacts will also be welded due to secondary collision, which will make the contacts heated and go bad. Therefore, sufficient attention must be paid on contact pressure [6].

But the patents and early testing technologies are aiming at the testing of static initial and final pressure, which is not enough for the study of the dynamic behavior of contact pressure on contacts. Most of the time, the dynamic contact pressure variation trend is needed for the study. The changes of the peak contact pressure and contact bounce based on different close phase angle are also important. Polyvinylidene fluoride (PVDF) piezoelectric films opportunely conditioned can exhibit piezoelectric and pyroelectric properties with a fast dynamic response. Moreover, they can be reduced to tiny compliant strips for embedding in a continuous elastic layer. They are perfect for dynamic measurement of contact pressure.

5.2 Test device

The AC contactor contact pressure dynamic testing device is composed of hardware and software part. The software part is composed of the parameter setting and modifying module, the document processing module, the debugging module, the test and trial operation module and so on. The principle block diagram is shown in Figure 3.

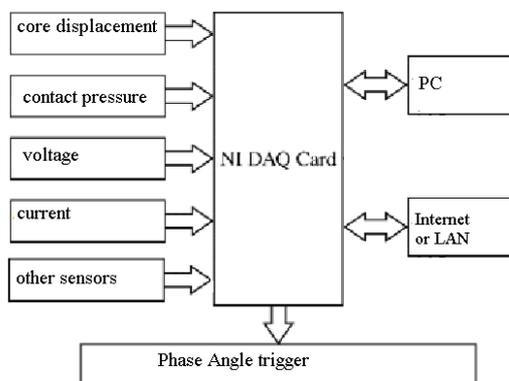


Figure 3. Principle diagram of the testing system

The hardware part is divided into upper machine and lower machine. The Upper machine is an industrial computer. The lower machine includes: high speed data, acquisition card, closing phase angle controller, signal measuring module, power supply and testing control circuit. The industrial PC is connected to the high-speed data acquisition card, the closing phase angle controller and the testing control circuit. The input and output of the signal measurement modules are connected respectively with the sample contactor and high-speed data acquisition card. The power supply powers the control circuit and other modules.

The signal measurement module includes: PVDF contact pressure sensors, charge amplifier and signal modulation circuit. The PVDF contact pressure sensor whose output is connected to the electric charge amplifier through shielding wire is installed on the static contact. The charge amplifier's output is connected to the signal modulation circuit through shielding wire, which is connected to the high-speed data acquisition card.

5.3 Pressure measuring principle

When the moving contact and static contact are closed, the contact pressure between them can be considered to be an impact stress. Since it is a vertical impact, it is also equivalent to an impact pressure. The impact force is passed on to the piezoelectric thin film, whose two surfaces produce corresponding charge by measuring which the contact pressure can be obtained.

The output value of typical charge amplifier circuit is determined by the piezoelectric constant $d_{33}(pC/N)$ and the feedback capacitance $C(pf)$. The low-frequency cutoff frequency is determined by the time constant RC .

When the frequency is much greater than $(1/2\pi) \times R \times C$, the amplifier output voltage $V_p(V)$ is $V_p = q/C = 1/C \times d_{33} \times F_p$. Where, $F_p(N)$ is the vertical force on the sensor surface, and q is the charge produced by the PVDF piezoelectric film.

The thickness of PVDF piezoelectric film is generally $30\mu m$, which makes cutting easy, and the size can be very small. In practical applications, the error caused by the thickness of the sensor is negligible, which makes PVDF completely in conformity with the test requirements of contactor contact pressure.

Sensors made of PVDF have high response speed (ns). They can capture transient signals timely and accurately. They also have a high sensitivity and large measurement range (0~20) GPa [7], which is far greater than the maximum contact pressure value of AC contactor. The vibration frequency of iron core impact and the contact vibration system is different. We can measure the frequency range of these vibration signals respectively, and then remove the vibration signals of the iron core and the outside world with a filter, thus identify the contacts contact pressure signal.

5.4 Experiment and result

A dynamic contact pressure testing of CJ20-25 was carried out in Hebei University of Technology. This AC contactor is a double breakpoint contact bridge type, so we paste contact pressure sensors on both static contacts.

During the test, the room temperature was 17 °C and humidity 21%. The sensitivity of the charge amplifier was set at 21 PCS, and gain at 0.1 K. The oscilloscope was YOKOGAWA DL750. 20 groups of data were collected continuously. The purpose is to observe the dynamic change trend of the contacts contact pressure, the changes of the peak contact pressure and the contact bounce based on different closing phase angle. Figure 4 shows the dynamic contact pressure waveform from different closing phase angle.

From the experimental results, the following preliminary conclusions can be obtained as follows:

(1) The impulse is the biggest when the contacts close at 0° or 180°. The contact's first bounce is violent, and the secondary is obvious. When the closing phase angle is around 30°, 70° and 220°, the contact closure time is shorter, the first bounce rate is small, the secondary bounce is not so obvious, the bounce time is shorter, and the overall closing process is smooth. When the closing phase angle is around 90° and 270°, the contact closure time is longer, the first bounce rate is great, the secondary bounce is obvious, the bounce time is longer, and the overall closing process is rougher.

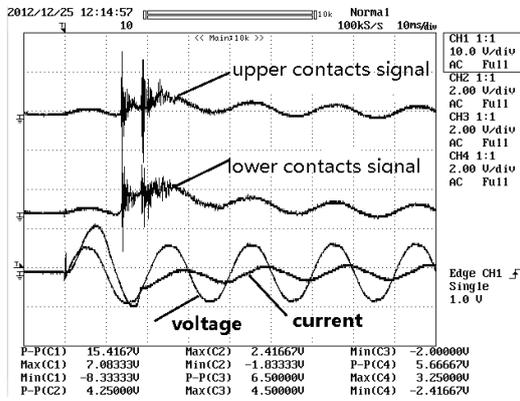


Figure 4. Waveform of contact pressure when close phase angle is about 0°

(2) The contact pressure signals can give more detailed contacts bounce information. When the bounce rate is small, especially when the contacts bounce stopped, the contact pressure is an AC pulsation, and this tiny displacement cannot be detected by a high speed camera [8].

The experimental results show that it is feasible to get the dynamic contact pressure of contacts using PVDF piezoelectric film which can not only reflect the length of the closing time when the contact close

at different phase angle, but the amplitude of the first and second bounce, and the smooth degree of the overall closing process. This method has more advantages compared with that of the high-speed camera. The dynamic contact pressure of contacts can be clearly and accurately obtained using this test method, and the contact bounce can be further revealed. The method can be transplanted to dynamic contact pressure testing of other electric equipment. We will do further research and improve its application level in the future. Figure 5 is Waveform of Contact Pressure after filtering processing.

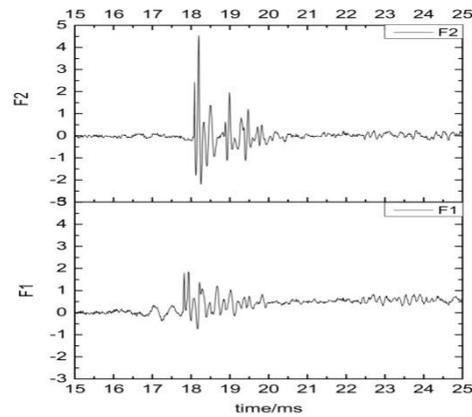


Figure 5. Waveform of contact pressure after filtering processing

Compared Figure 2 with Figure 5, it can be seen that the simulation results and the actual measurement of contactor contact pressure signals are very similar, but the frequency and intensity of actual contacts vibration are far greater than the simulation results. It is mainly because the actual working condition of the contactor is more complex. Where waveform F1 and F2 are in Figure 5 are the upper and lower contacts pressure signals. The maximum upper contacts pressure F1 is bigger, which shows that the stress of the two contacts is not uniform. The reason may be that the contacts supporters are shaking when collision happened. The waveform F2 has three obvious bounces, and the interval between the first and second bounce is about 1 ms, the interval that between the second and third bounce decreased significantly is only about 0.5 ms. The amplitude also becomes smaller which is very similar to the recorded waveform in Figure 2.

6 CONCLUSIONS

A multi-body dynamics simulation model of CJ20-25 AC contactor was established with Pro/E (Pro/Engineer) in this paper. A coupling simulation with machine, electric, magnetic on the contactor has been realized in this model. Dynamic parameters

which were called use the secondary development technology of ADAMS. The dynamic contact pressure signal of an AC contactor was obtained with ADAMS's own simultaneous solution such as electromagnetic suction, kinematics and dynamics equations. The simulation results and actual measurement of contactor contact pressure signals are very similar. However, the complexity of the measured contacts vibration is greater than the simulation results because the actual working condition is more complex.

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