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AC Contactor Electromagnetic Mechanism Dynamic Simulation Study

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Abstract: In this paper, we study the application of Maxwell 3D and ADAMS software for simulation and analysis of electromagnetic system, with UG software for AC contactor and main contact system of electromagnetic system. We then study the influence of harmonic on type CJX2-40 AC contactor main contact system and operation characteristics. To establish a three-dimensional finite element model of electromagnetic mechanism of AC contactor, we take Maxwell 3D software, on the model of finite element mesh, the calculation of different closing sine excitation and containing under harmonic excitation angle electromagnetic system. For the static and dynamic characteristics of AC contactor, static magnetic field distribution and the suction characteristic curve drawing, we do a comparative study of the results of the simulation, analysis of the influence of harmonics on the AC contactor motion characteristics.

Keywords: CJX2-40 AC contactor, dynamic simulation, maxwell 3D,

1. THE BASIC THEORY OF AC CONTACTOR

AC contactor is widely used in circuit switching and control circuit of electrical appliances. It uses the main contact breaking circuit, to perform the control instruction with auxiliary contact. The main contact is generally only a few on the normally open contact, and the auxiliary contacts are generally has the contact normally open and normally closed functions in two pairs, small contactor often in main circuit and an intermediate relay with the use of.

The contacts of the AC contactor are made of silver tungsten alloy, with good conductivity and high temperature resistant ablative [1-4].

AC contactor is composed of four parts: (1) the electromagnetic system, including attracting coil, a movable iron core and the static iron core; (2) the contact system, comprises three pairs of main contact and two normally open, two normally closed auxiliary contact and the moving iron core, it is together mutual linkage; (3) out arc device, AC contactor generally larger capacity are arc extinguishing device, in order to quickly cut off the arc, avoid burning the main contact; (4) insulation casing and accessories, all kinds of spring, a transmission mechanism, a short circuit ring, terminal etc.

The working principle of AC contactor: when the coil is energized, the static iron core to generate electromagnetic force, the moving core pull, because the contact system is with the moving iron core are linked, so moving core drive three movable touch bridge running at the same time, the contact is closed, thereby switching power supply. When the coil power, suction disappeared, moving core linkage part depends on the reaction force of the spring and the motion, the main contact is disconnected and cut off the power supply.

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2. THE WORKING PRINCIPLE OF CJX2-40 TYPE AC ELECTROMAGNETIC CONTACTOR

The working process of CJX2-40 type AC electromagnetic contactor: contactor movable contact and fixed in the insulating bracket, bracket and connected with a moving armature insulation. When the electromagnetic coil connected to the power contactor, will produce a strong magnetic field, the armature present electromagnetic force, armature, bracket, a movable contact three together action (normally closed off, normally open contacts).

After power on time, to generate the magnetic field between the dynamic, static iron core, an armature is in the open position, it will be affected by the electromagnetic force and the counterforce spring (spring towers) interaction [5]. When the electromagnetic force greater than the spring reaction force, the armature is attracted to the static iron core, on the one hand, a compression spring, a certain potential energy savings, release to disconnect; hand with the moving iron core contact bracket connected drives the movable contact close to the static contact, the contact spring temporarily out of action. When the movable contact and the static contact just met, the armature to continue downward, the three contact springs are compressed; presentation and tower spring reaction force similar to the armature and the moving contact after the movement speed will start to slow down, the armature continued movement until the closed position, but static is still a very small gap between the iron core and the armature iron. Contact spring is compressed to

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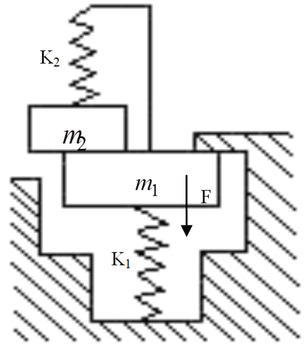


Fig. (1). Dynamic model of contactor.

its final position, the moving contact and the static contact close contact, to complete the task on the main circuit [6].

Needs to be pointed out is, beating contact closed and dynamic, a static iron core closure will cause contact. The movable contact head, static contact from it and contact (not yet completely closed armature) to contact support motion Bi (all closed armature), which produce super. In addition, buffer exists; a static iron core position also there will be some fluctuation [7-10].

Disconnect the power supply when the armature coil, in the tower under the action of spring in the released position, dynamic and static iron cores to form a working air gap. At the same time, because the armature and the moving contact for the linkage relation, the moving contact is in the open state, dynamic, static contact distance is the distance between the contacts. When the voltage of coil is reduced to a value or zero, on the end surface of the core flux is reduced, the electromagnetic suction decreased, when the electromagnetic force is less than the spring reaction force, moving core release effect this reaction force, so as to drive the movable contact disconnect circuit.

3. DYNAMIC MATHEMATICAL MODEL OF AC ELECTROMAGNETIC CONTACTOR

In engineering design, electrical appliances are usually according to the static characteristic of electromagnet to judge the working characteristics, but, through process electrical appliance is not really depends on the static characteristics, but dynamic characteristics, working process that changes with time [11].

The switch electric appliance, such as a contactor, electric appliance switch on the effect in the process of impact energy and closing speed greatly to the life of the mechanical and electrical life, in action in the process of the contactor, contact collision so as to produce a beat, in addition, the collision also occurred between dynamic, static iron core, second contact beat generation. For the two time to reduce the contact bounce, in addition to the use of good suction and force characteristic with in order to reduce the collision energy, electromagnetic system need to be equipped with the buffer device. CJX2-40 type AC electromagnetic contactor in the static iron core mat with Silicon rubber buffer can absorb excess energy core during collision. That is to say, the dynamic process is the main factor affecting the reliability of electrical apparatus.

The dynamic model of AC contactor has been shown in Fig. (**1**). With the armature and the moving contact of mass m_1, dynamic quality contact bridge is m_2, a reaction spring and the contact spring stiffness is k_1, k_2 respectively, the coil after the power is switched on, before and after dynamic and static contact, quality of moving parts from $m_1+ m_2$ into $m_1+ m_2$, and the spring stiffness of the system from the k_1 movement become ($k_1+ k_2$), until the dynamic and static iron core is attracted reliably, complete the whole closing process.

The dynamic process of electromagnetic mechanism includes two processes, attracting and releasing. Suction moving process is usually divided into two stages: the first stage suction dynamic process far from the coil current is switched on the power supply to the current growth, this stage suction is less than or equal to the force, the moving core yet movement, called touch process. The second stage, the suction is greater than the force, the moving core to start moving, called motion process. With the increase of the moving iron core displacement, gas gap decreases, until the dynamic, static iron core is fully closed, during both contain the electromagnetic heating, mechanical process, etc.

The dynamic process of AC contactor, the magnetic field must follow the Maxwell equation in the circuit must follow the voltage balance equation in the motion must follow the Darren Bell equation of motion, as well as in the heat on the road should be based on the heat balance equation, there are correlations between these equations, constitute a differential equation describing the dynamic process of the group [12, 13]. That is,

$$\begin{cases} \Psi = f_1(i,\delta) \\ F_x = f_2(W_\mu) \\ u = iR(\theta) + \dfrac{d\Psi}{dt} \\ m\dfrac{d^2x}{dt^2} = F_x - F_f(x,\dfrac{dx}{dt}) \\ \dfrac{d\theta}{dt} = f_3(P,t,\theta_0,D_{0T},H_x) \end{cases} \quad (1)$$

In the formula, I,Ψ----- respectively, the coil current and electromagnetic system flux;

u----- the excitation voltage coil;

R----- coil resistance, is a function of the θ ;

m----- the electromagnetic system moving parts was counted as the core polar center quality;

x----- the electromagnetic system moving parts was counted as the core polar center displacement;

t-----time;

F_x、F_f-----corresponding to the core pole for conversion at the center of the suction and movement dynamic reaction force and the spring load displacement function of anti force, and the air resistance is the function of dx/dt ;

W_μ---- magnetic electromagnetic system, is the function of i、Ψ;

θ、θ_0----- the corresponding to the coil temperature and ambient temperature;

P----- the power consumption of the electromagnetic mechanism;

D_{0T}、H_x----- coil diameter and height respectively.

Due to the dynamic process lasted a very short electromagnetic system, and the existence of thermal inertia, so $d\theta/dt$ hot, hot change is very small, can be neglected, while ignoring the vortex core if the meter and the core magnetic reluctance, but, these equations are transformed and integrated, suction process of electromagnetic mechanism can be described as type (2) equation of state group:

$$\begin{cases} \dfrac{d\psi}{dt} = u(t) - i(t)R \\ \dfrac{dv}{dt} = \dfrac{F_x - F_f(x, \dfrac{dx}{dt})}{m} \\ \dfrac{dx}{dt} = v \\ \Psi\big|_{t=0} = \Psi_0 = 0, v\big|_{t=0} = v_0 = 0, x\big|_{t=0} = x_0 = 0 \end{cases} \tag{2}$$

In the formula,

u、i----- respectively coil voltage and coil current;

Ψ----- the electromagnetic system of full flux;

F_x、F_f ----- the dynamic electromagnetic force and movement anti force;

x----- the displacement of moving parts;

v----- the moving iron core at any one time speed.

4. SIMULATION OF DYNAMIC CHARACTERISTICS OF AC ELECTROMAGNETIC CONTACTOR OF MAXWELL 3D

4.1. Three Dimensional Transient Field Analysis Theory

The Maxwell 3D transient motion solver has similar dynamics solving function, can be used to calculate electromagnetic problems that involve movement. Its features are as follows:

1) Solving the electromagnetic field: nonlinear material properties can be magnetic materials, permanent magnet, anisotropic nonlinear (linear) and super conductor, are solved in the time domain;

2) Unrestricted rotational and translational motion mode: define settings window on the object in the moving parts;

3) And the circuit coupling: the excitation source can be a sinusoidal voltage (current), current density, can be coupled with external circuit;

4) Mechanical transient simulation: mechanical quantities, such as quality, load, damping, inertia and initial speed, can be defined as a constant or a function;

5) Can the calculation of eddy current and hysteresis loss: definition of force / torque and eddy current, iron loss, when solving can be stopped at any time (start) without data loss [9].

It can be mainly used for analysis of rotating machinery, magnetic bearing, electromagnetic brake, solenoids calculation.

A. A time-varying magnetic field equations

The differential form of Maxwell equations for

$$\nabla \times v \nabla \times A = J_s \sigma \frac{\partial A}{\partial t} \sigma \nabla v + \nabla \times H_c + \sigma v \times \nabla \times A \tag{3}$$

In the formula,

H_c is the permanent magnet coercive force;

v is the velocity of a moving body;

A is the magnetic vector;

J_s is the current density.

Transient solver using a frame of reference is fixed on the model of a part of the speed v of 0.

The moving object is fixed in its own coordinate system, the total derivative partial derivative into the equations of motion, thus becomes

$$\nabla \times v \nabla \times A = J_s \sigma \frac{\partial A}{\partial t} \sigma \nabla v + \nabla \times H_c \tag{4}$$

B. Solid conductor

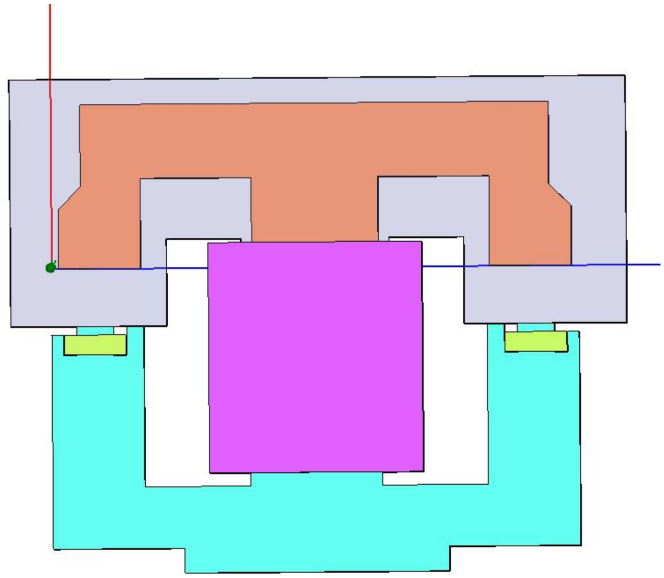


Fig. (2). Dynamic model of 3D electromagnetic mechanism.

Solid conductor is very big, can use the description of finite element, the skin effect it is not only related with the frequency of the system, but also with the relevant positions around the conductor. Based on the Ampere's law, the total system current density

$$J_t = \sigma \frac{dA}{\vartheta t} \sigma \nabla v \tag{5}$$

can be summarized as

$$J_t = \sigma \frac{dA}{\vartheta t} + \frac{\sigma}{l} \nabla v_b \tag{6}$$

or

$$J_r = J_e + J_s \tag{7}$$

Among them, v_b is the voltage conductor end difference, J_e is the eddy current density, J_s s the source current density [7].

C. Solid conductors with current source

For solid conductors with current source, the total current is known; the source current component is unknown. Transient solver using current equation (10) calculates the N conductor current source.

$$\iint_{\Omega_c} (\sigma \frac{\partial A}{\partial t} + J_s) d\Omega = \iint_{\Omega_c} (\frac{\sigma}{l} v_b) d\Omega = I_t \tag{8}$$

In the formula, Ω_c is a conductor cross section, It is the Known total current, It is the source current component to be solved, It is the total current density.

D. Solid conductor with voltage source

For solid conductors with a voltage source, the total voltage is known, the total current density is unknown. Transient field solver is calculated by use of an unknown quantity from the circuit equations are derived solid conductor equation. The circuit equation is derived for the

$$\iint_{\Omega_c} (\sigma \frac{\partial A}{\partial t} + J_s) d\Omega = \iint_{\Omega_c} (\frac{\sigma}{l} v_b) d\Omega \tag{9}$$

E. The translational motion

Translational motion equation

$$ma + \lambda s = F_{comp} + F_{load} \tag{10}$$

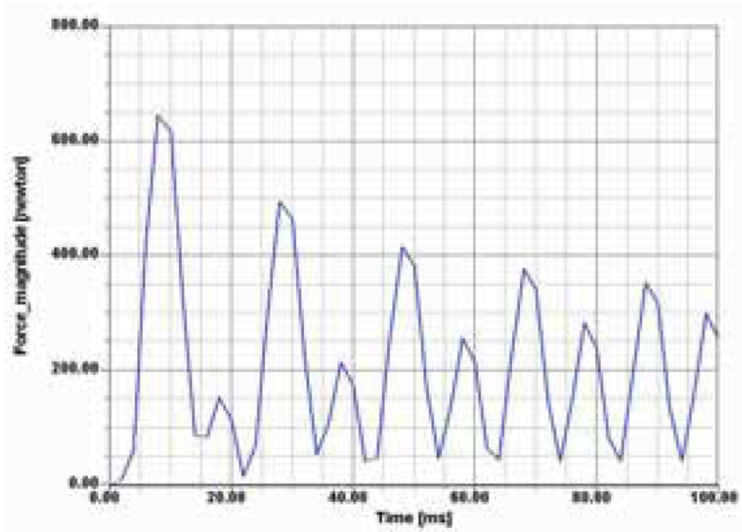
In the formula, m is the mass of an object, kg, a is acceleration, m/s^2,λ *is* damping, $N,s/m$; F_{comp} is electromagnetic force, F_{load} is the force, N.

4.2. Three Dimensional Electromagnetic Transient Analysis Models as Building Mechanism

Dynamic simulation model can be directly to the static model import, only need to model the moving parts on the basis of re defined. The model shown in Fig. (**2**), in this case, refers to the movement of parts in the moving core, moving core in the guarantee to the normal movement condition, set it within Band, and set the Band property to air material.

4.3. Simulation Of Dynamic Characteristics Under Sinusoidal Excitation

The dynamic characteristics usually refer to the electromagnetic force F, Coil flux ψ, The displacement of moving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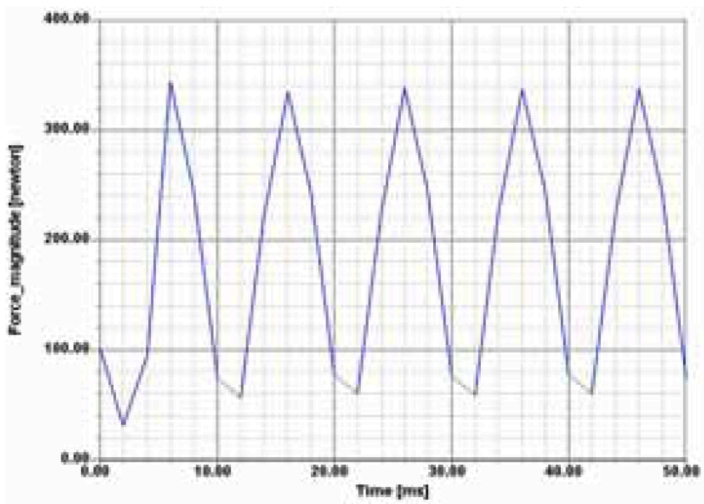
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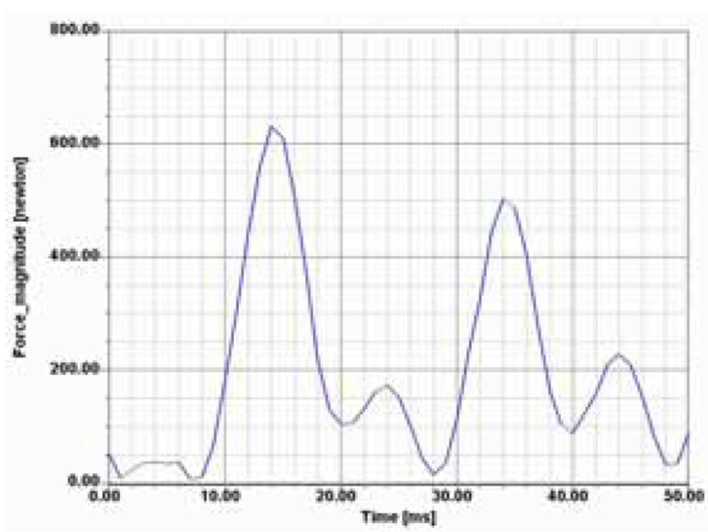
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Fig. (**3**). Contd….

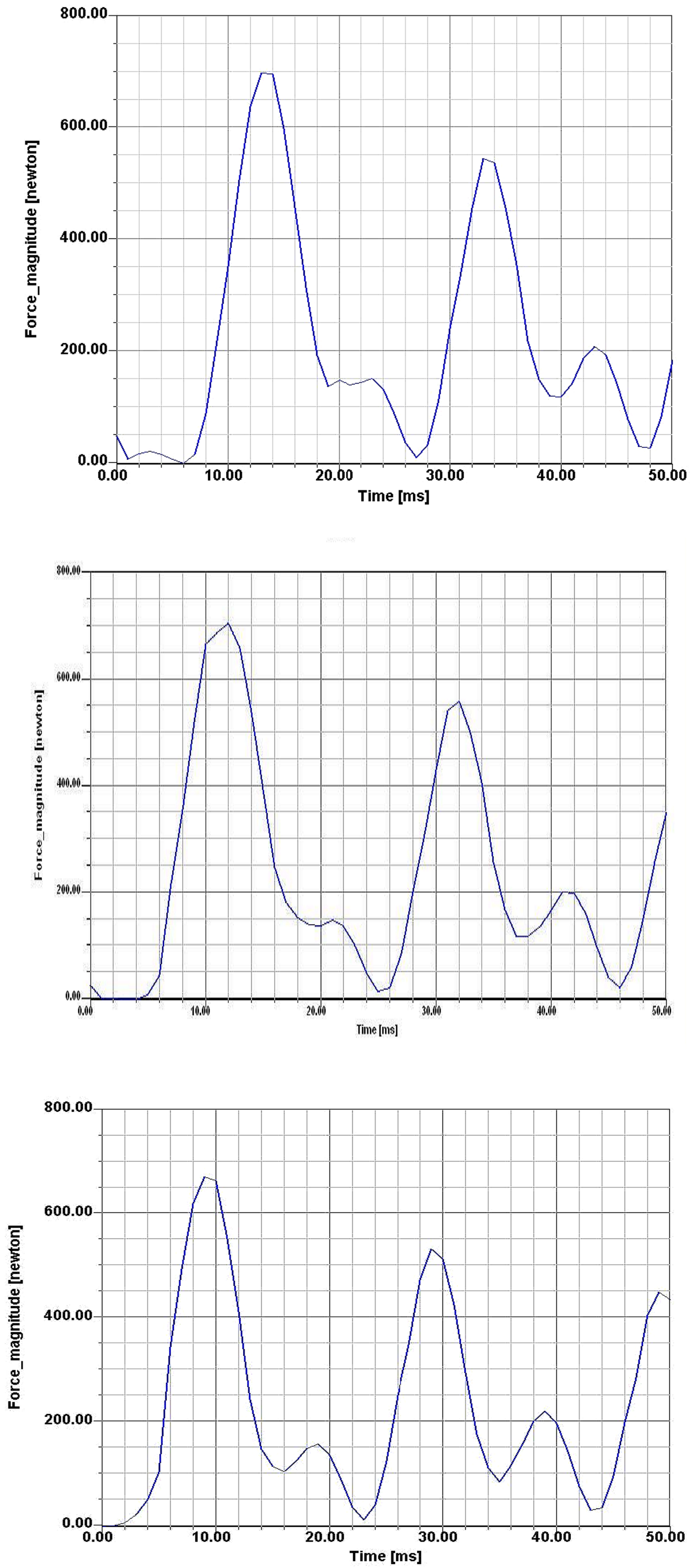
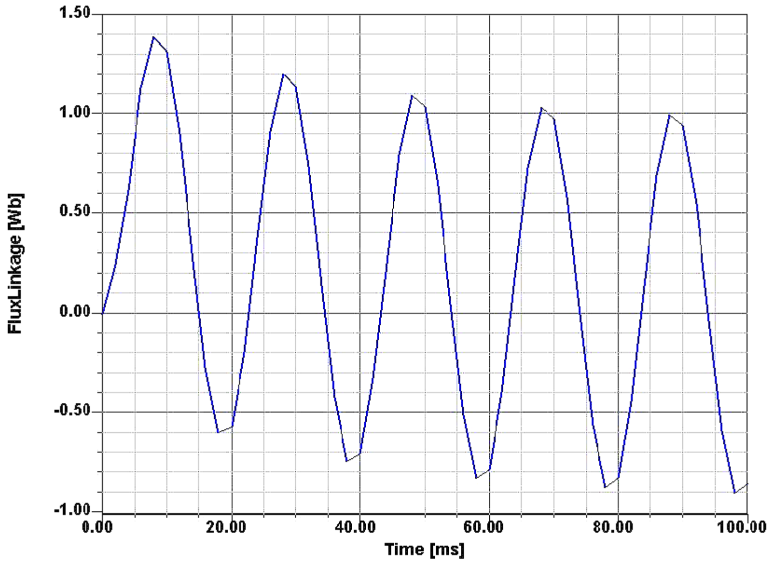


Fig. (3). The characteristic of electromagnetic suction under sine excitation.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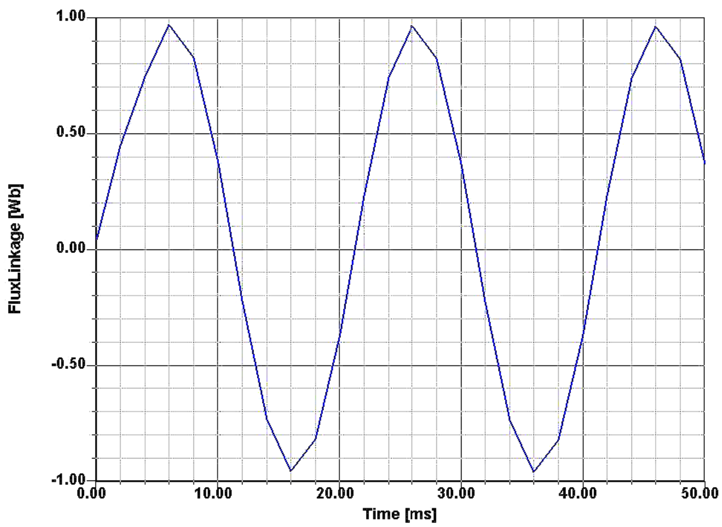
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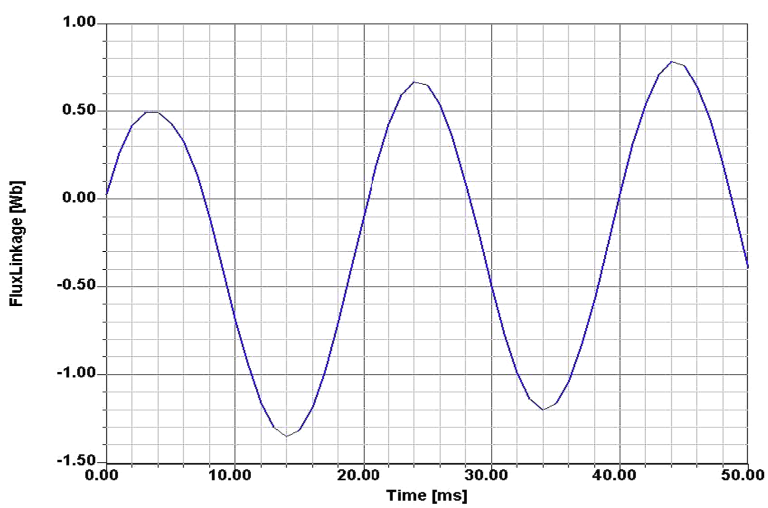
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Fig. (**4**). Contd….

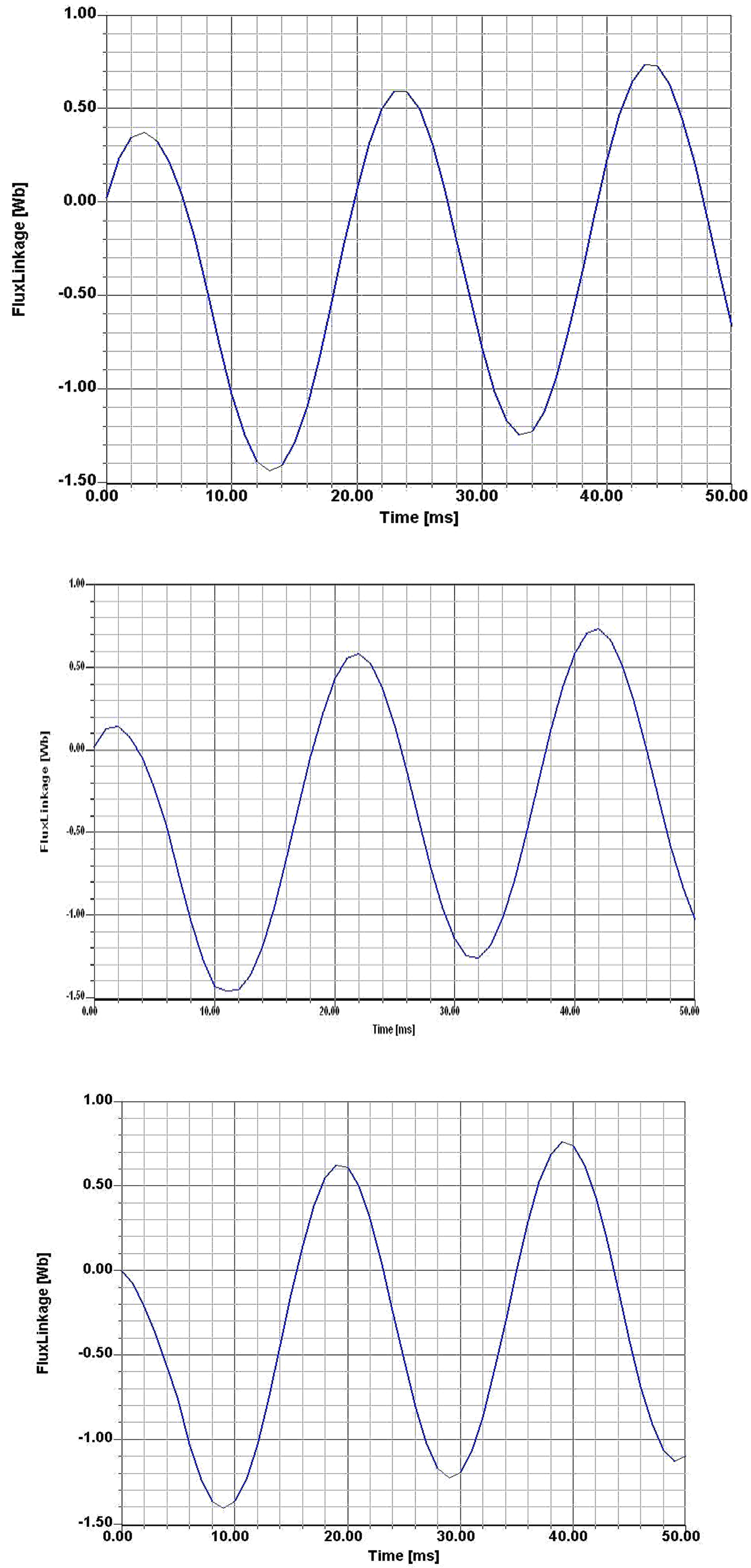

Fig. (4). The characteristic of core fluxlinkage under sine excitation.

parts x, the moving speed and the velocity of movement dx/dt and acceleration d^2x/dt^2 change over time.

Fig. (**3**) from left to right, from top to bottom are electromagnetic suction characteristic curves at 0°, 45°, 90°, 105°, 135°, 180° in the closing phase angle.

From the above chart, it can be obtained under sinusoidal excitation, in different closing phase angle when the electromagnetic force is certainly different. 1) suction peak time, namely pull in time, in the closing phase angle of 0° and 45° is about 6ms when the electromagnetic force reaches the maximum value, the closing phase angle of90° and 90° around 14ms electromagnetic force to reach the peak, while the phase is peaked at 135° and 180° time was about 10ms. 2) different change trend of suction with time, the differences between the first peak and second electromagnetic suction peak is obvious, but the curve can be seen, the gap between the two peaks is more and more small uniform. 3) minimum suction value, minimum suction value on the contactor can reliably pull play a decisive role, closing phase angle because of the different minimum electromagnetic suction change.

Fig. (**4**) is a sinusoidal excitation characteristic curves of different closing coil flux phase angles. Clearly that flux characteristics of different brings the different closing phase angle.

CONFLICT OF INTEREST

The authors confirm that this article content has no conflict of interest.

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Declared none.

REFERENCES

[1] M.A. Juds, and J.R. Brauer, "AC contactor motion computed with coupled electromagnetic and structural finite elements," *IEEE Trans. Magn.*, vol. 31, pp. 3575-3577, 2011.

[2] R. Gollee, and G. Gerlach, "An FEM-based method for analysis of the dynamic behavior of AC contactors," *IEEE Trans. Magn.*, vol. 36, pp. 1337-1340, 2010.

[3] G. Mur, "Finite-element modeling of electromagnetic fields," In: Proceedings of the 1996 3rd International Conference on Software for Electrical Engineering Analysis and Design ELECTROSOFT, 2000, vol. 96, pp. 177-186.

[4] R. Gollee, "FEM-based method for analysis of the dynamic behavior of AC contactors," *IEEE Trans. Magn.*, vol. 36, no. 41, pp. 1337-1340, 2013.

[5] Y. Kawase, "3-D finite element analysis of operating characteristics of AC electromagnetic contactors," *IEEE Trans. Magn.*, vol. 30, no. 5, pp. 3244-3247, 1994.

[6] S. Z. Djokic, J.V. Milanovic, and D.S. Kirschen, "Sensitivity of AC coil contactors to voltage sags, short interruptions, and under voltage transients," *IEEE Trans. Power Del.*, vol. 19, no. 3, pp. 1299-1307, July, 2012,

[7] M. Wada, "Dynamic analysis and simulation of electromagnetic contactors with AC solenoids," In: IECON Proceedings (Industrial Electronics Conference), 2012, vol. 4, pp. 2745-2751

[8] W. Li, J. Lu, H. Guo, and W. Li "AC Contactor Making Speed Measuring and Theoretical Analysis," In: Proceedings of the 50th IEEE Holm Conference on Electrical Contacts and the 22nd International Conference on Electrical Contacts, 2004, pp. 403-407

[9] X. Li, D. Chen, Z. Li, and W. Tong, "Numerical analysis and experimental investigation of dynamic of AC contactors concerning with the bounce of contact," *IEICE Trans. Electron.*, vol. 8, pp. 1318-1323, 2013.

[10] J.H. Kiely, H. Nouri, F. Kalvelage, and T.S. Davies, "Development of an application specific integrated circuit for reduction of contact bounce in three contactors. Electrical Contacts," In; Proceedings of the Annual Holm Conference on Electrical Contacts, 2010, pp. 120-I29.

[11] H.K. Hoidalen, and M. Runde, "Continuous monitoring of circuit breakers using vibration analysis," *IEEE Trans. Power Del.*, vol. 20, no. 4, pp. 2458-2465, 2005.

[12] M. Landry, F. Lonard, and R. Beauchemin, "An improved vibration analysis algorithm as a diagnostic tool for detecting mechanical anomalies on power circuit breakers," *IEEE Trans. Power Del.*, vol. 23, no. 4, pp. 1986-1994, 2008.

[13] J. Huang, X.G. Hu, and X. Geng, "An intelligent fault diagnosis method of high voltage circuit breaker base on improved EMD energy entropy and multi-class support vector machine," *Elect. Power Syst. Res.*, vol. 81, no. 2, pp. 400-440, 2011.

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