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Analysis of Energy Transfer Process of Vehicle Horn

Jifeng GUO, Honge REN*, Zhiqiang Ma, Yan MA

Northeast forestry university, Heilongjiang, Harbin, China
{ gjf1000@126, renhonge163@163.com, zhiqiang1980@163.com, myan@vip.163.com, }

Abstract. The energy transfer process of vehicle horn were analyzed through the energetic coil current, magnetic force, and displacement curves which had gotten before, and the process was happened in stage of the action, transaction and reciprocating vibration. The conclusions are of great value for further optimizing of reliability of the electro acoustic device such as electromagnetic horn.

Keywords: Vehicle horn, vibration, electrical-mechanical energy transfer, coupled mechanical-electromagnetic characteristics.

1 Introduction

Vehicle horn(generally for mechanical electromagnetic horn)is a kind of transducer that converts electrical energy into sound energy. The electromagnetic horn which is used for warning signal has a simple structure, low cost, easy maintenance and repair, etc and has widely been used in water and land transportation of DC power supplying, becoming an indispensable key components of all kinds of transportation safety system[1].

The theory modeling and simulation analysis of electro acoustic transducer involves electromagnetism, structural dynamics, fluid mechanics, acoustics, etc. The manufacturing technology of electromagnetic vibration horn in our country has become mature, but compared with foreign products there is a big gap at product quality and reliability. Previous research is more about a single analysis the horn diaphragm of structural dynamic characteristics[2-3], The horn of static magnetic fields distribution and suction characteristic of electromagnetic pulse is analyzed by academics[4-7], and formed the computational method of the electromagnetic coupling in the mechanical action process. The virtual prototype model of electromagnetic horns including contact breaking arc physical process was built by commercial finite element analysis software ANSYS and combined use of multi-body dynamics software ADAMS, respectively, completed the simulation analysis of the vibration characteristics and experimental tests[8-10]. In this paper, on the basis of previous research, and according to the principle of electromechanical energy conversion, mechanical electromagnetic horn was studied in power input, arc loss, resistance loss, mechanical work, magnetic field energy, kinetic energy, potential energy, sound energy from touches development phase transition to the steady stage of reciprocating vibration, and the steady state in the process of reciprocating

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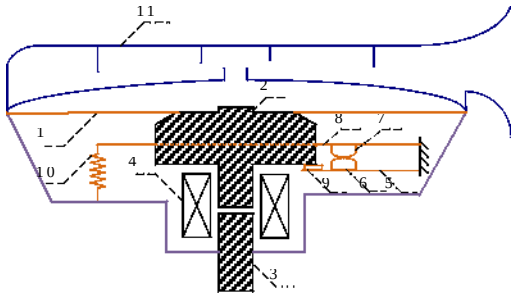
vibration arc, arc and the cooperate relationship between electromagnetic suction and mechanical reaction, the energy conversion process in the contact closure, finally a reasonable criterion about whether electromagnetic horn can access to steady-state process of reciprocating vibration is presented.

2 Working principle and energy relationship

Electromagnetic horn includes dynamic iron core, static iron core, the excitation coil and plate shell, etc. Contact system includes dynamic contact, moving contact spring, static contact, static reed and insulating diaphragm [8]. Diaphragm and the trumpet constitute the vocal vibration parts, as shown in Fig.1.



1. Diaphragm; 2. Dynamic iron core; 3. Static iron core; 4. Coil; 5. Dynamic reed; 6. Dynamic contact; 7. Static contact; 8. Static reed; 9. Insulating diaphragm; 10. Screw; 11. Trumpet

Fig. 2. Simple construction diagram of electromagnetic horn

Coil power on the DC current can generate magnetic field, the electromagnetic force driving dynamic core and diaphragm move downward, then dynamic iron core promote the normally closed contact breaking, excitation current reduce to zero. When electromagnetic suction is lower than the reaction force generated by the spring and diaphragm mechanical structure generated the move iron core will move from bottom to top by the reaction force. The contact recovering closed state and conducing excitation coil current which generate the magnetic force again and attracting dynamic iron core repeat the above process. In this process the diaphragm generates harmonic vibration under periodic external force, cause the surrounding air to fluctuate, generate sound and spread out by the horn.

Seeing the electromagnetic horn as a two port device : mechanical port and electrical port. Shifting out the resistance loss and mechanical loss, respectively with the coil resistance R and arc resistance R_c (zero when the arc extinguish, contact resistance when contact is closed), moving drag coefficient, and regardless of the dielectric loss of ferromagnetic medium, the device center will become a lossless core,

air gap and without copper loss, mechanical loss and dynamic coupling coil of lossless magnetic energy storage system, as shown in Fig. 2.

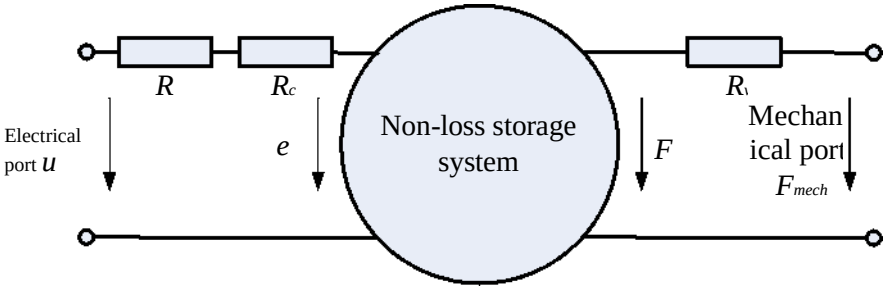


Fig. 2. Schematic of mechanical energy and electromagnetic energy conversion process

As shown in Fig.2, for single incentive non-loss storage system, in time $\mathrm{d}t$, the power input is

$$\mathrm{d}W_e = Ei\mathrm{d}t = i\mathrm{d}\psi + i^2(R+R_c)\mathrm{d}t \tag{1}$$

The change of coupling field magnetic energy is

$$\mathrm{d}W_m = \frac{\partial W_m}{\partial \psi}\mathrm{d}\psi + \frac{\partial W_m}{\partial y_{mech}}\mathrm{d}y_{mech} \quad i\mathrm{d}\psi = F_e\,\mathrm{d}y_{mech} \tag{2}$$

Mechanical energy output is $\mathrm{d}W_{mech} = F_e\mathrm{d}y_{mech}$, for coupling field, ordering input energy is positive, the output is negative. According to the above relations, the magnetic energy $\mathrm{d}W_m$ increment includes two parts: the magnetic energy increment caused by the flux change $\frac{\partial W_m}{\partial \psi}\mathrm{d}\psi$, equaling the difference between the power absorbed from net power $\mathrm{d}W_e$ and the energy consumption of resistance; the magnetic energy increment caused by changes in displacement $\frac{\partial W_m}{\partial y}\mathrm{d}y$, equaling the output of the differential mechanical negative energy $\mathrm{d}W_{mech}$. In the process of energy conversion, as a coupling magnetic field can be either input or output energy from electrical system, also can be either output or input energy for mechanical system, its state mainly depends on the constraints of the magnetic chains ψ and displacement of moving part y [11].

Moving iron core and the vibration system composed of diaphragm meet the principle of conservation of energy under the action of external mechanical force in the process of the reciprocating vibration, external do mechanical work with the system kinetic energy and elastic potential energy and the output of the sound energy (energy dissipation of air damping n) keep conservation. $F_e\mathrm{d}y_{mech}$ can be rewrite into electromagnetic horns' mechanical system of kinetic energy and elastic potential energy (diaphragm, moving contact spring), and the change of acoustic emitted energy, Accordingly type (2) can be rewritten as

$$i\mathrm{d}\psi + \mathrm{d}=_{m} W \mathrm{d} W_{kinetic\ energy} + \mathrm{d}W_{potental\ energy} \mathrm{d}W_{sound\ energy} \quad (3)$$

$W_{kinetic\ energy}$ is the sum of the kinetic energy of the moving iron core, diaphragm and the moving contact spring, namely $_{kinetic\ energy} = \sum m v$; $W_{potential\ energy}$ is

$$W \quad \frac{1}{2} \quad {}_{2}; \quad {}_{i\,i}$$

$$i$$

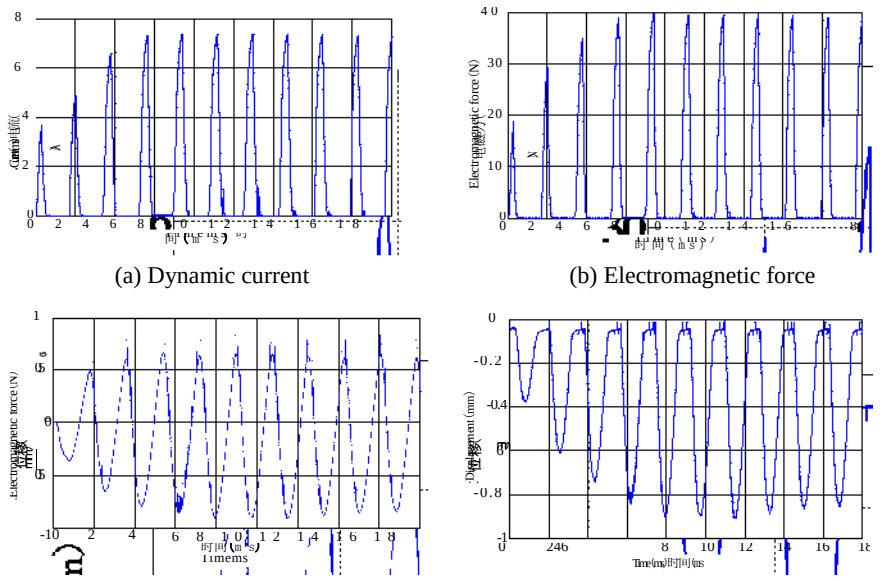
the sum of elastic potential energy of diaphragm and moving contact spring,

namely $W_{potential\ energy} = \sum \frac{1}{2} k_i^{2}\ y$

$$i$$

3 Mechanical and electrical energy conversion process

As shown in Fig. 3 according to the simulation of correct virtual prototype model of electromagnetic horn, we can analysis to get the curve of voice coil current, electromagnetic force, the moving iron core displacement and the dynamic contact



(a) Dynamic current (b) Electromagnetic force

(c)Moving iron core displacement (d) dynamic contact displacement

displacement, in the process from the coil electrifying to stable as a result. Complete working process can be divided into the touch, transient and steady state process of reciprocating vibration [6].

Fig 3. Simulation results by using virtual prototype

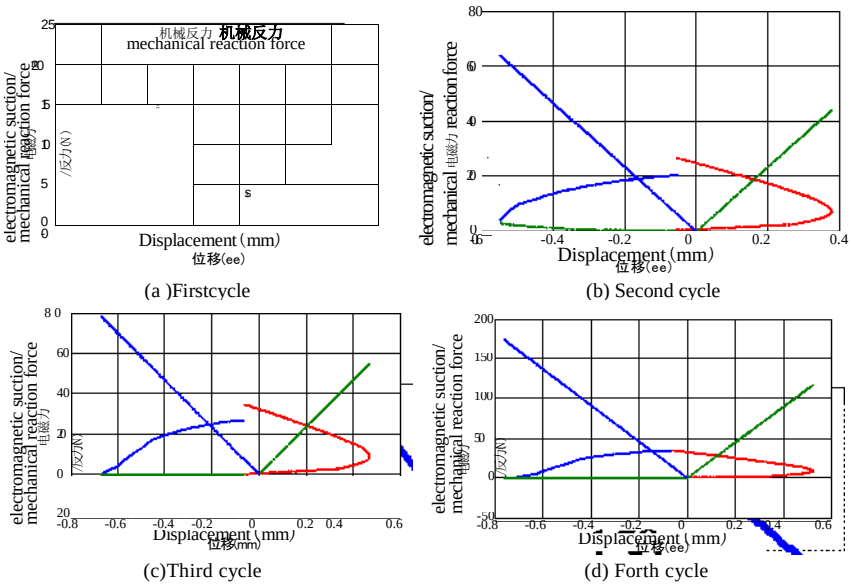


Fig. 4. Relationship between attraction force and mechanical force during whole operation

Horns can achieve stable reciprocating cycle vibration, which is inseparable energy accumulation in the process of early touches and transition. As shown in Fig.4 is the time-varying cooperate relationship between dynamic electromagnetic suction and mechanical reaction force, including the process of touches, transient and steady reciprocating vibration state of mechanical electromagnetic horn.

The stage of touches coil began to electricity, and the electromagnetic force is greater than the mechanical reaction force, thus leading moving iron core drives the diaphragm downward movement. In the process of transition, the displacement of moving iron core and diaphragm can be represented as y_c , the mechanical work of electromagnetic suction in this period of time can be represented as, $\int_0^{y_c} F_1 dy$, the diaphragm elastic potential energy can be represented as $\int_0^{y_c} ky_d y$, now with the kinetic energy of the moving iron core is

$$W_d = \int_0^{y_c} (F_1 - ky)dy \tag{4}$$

If initial pressure of spring system is F_0, the elastic potential energy of spring can be expressed as

$$W_p = \frac{1}{2} k_c y_{20}^2 \tag{5}$$

k_c -- the spring equivalent stiffness;

y_{20}-- the deformation of spring in contact location.

When $W_{1d} > W_p$, the moving iron core with the rest of the kinetic energy can make contact into the arc state. At this time, electromagnetic suction of 12 N ,by the above [6] stable energy conversion mechanism of a reciprocating motion process, during the arc ,the electromagnetic force do positive work for mechanical system and makes displacement amplitude of moving iron core gradually increasing, and makes the moving iron core upward movement cross the initial position in the return recoil and makes contact closure time prolong, providing electromagnetic force continue doing positive work to mechanical systems. After the point s_1 , electromagnetic suction will less than mechanical reaction force, reducing moving iron core movement speed. As shown in Fig.4 (a), upward return movement exists between point s_2 and point s_3 , where electromagnetic suction less than the mechanical reaction stage, but with previously stored kinetic energy smoothly completed through s_3 where electromagnetic suction is greater than the mechanical reaction again. This cycle the downward movement displacement amplitude of moving iron core is 0.17 mm, the corresponding mechanical reaction force is to 21 N, the upward movement displacement amplitude of moving iron core is 0.12 mm, the corresponding mechanical reaction force is to 15 N.

When moving iron core second run into spring making contacts breaking, it has a bigger coil current than the first time, so the electromagnetic suction increased to 20N. As shown in Fig.4 (b), this cycle the downward movement displacement amplitude of moving iron core is 0.57 mm, the corresponding mechanical reaction force is to 63N, the upward movement displacement amplitude of moving iron core is 0.38 mm, and the corresponding mechanical reaction force is to 42N. When moving iron core third run into spring making contacts breaking, it has a bigger coil current than the second time, so the electromagnetic suction increased to 28N. As shown in Fig.4 (c), this cycle the downward movement displacement amplitude of moving iron core is 0.7mm, the corresponding mechanical reaction force is to 78 N, the upward movement displacement amplitude of moving iron core is 0.48 mm, and the corresponding mechanical reaction force is to 54N. When moving iron core forth run into spring making contacts breaking, it has a bigger coil current than the third time, so the electromagnetic suction increased to 36N. As shown in Fig.4 (d), this cycle the downward movement displacement amplitude of moving iron core is 0.8mm, the corresponding mechanical reaction force is to 170 N, the upward movement displacement amplitude of moving iron core is 0.5mm; the corresponding mechanical reaction force is to 115N. The electromagnetic horn has entered a steady process of reciprocating vibration.

Fig.5 is corresponding closing time in the process. Touched stage which is completed by static acceleration process, thus the closing time is the longest：2.7ms. During the first cycle in the transitional process, contact has the first acceleration and second deceleration characteristics, the closing time dropped to 0.7ms. In the second cycle, the contact closure time increase 0.2ms than first cycle, in the third cycle, the contact closure time increased 0.1 ms, eventually in the steady state stage the closure time is stability to 1ms. In the transition process, the recoil distance which from upward return movement of moving iron core is constant improvement , providing the contact closure time increased; therefore extended the rebuilding process of coil

current, making electromagnetic suction in the process of touches and transition increase.

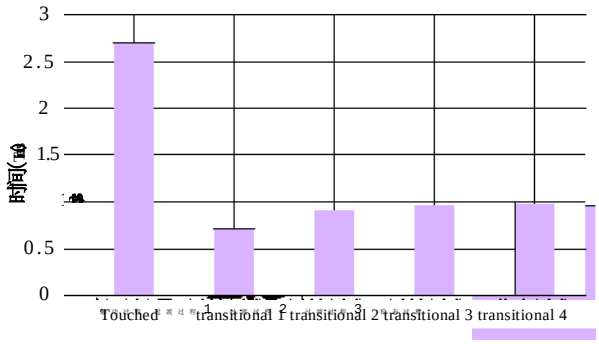


Fig. 5. the rules of keeping contact time

From Fig.3 we can see in the first two motion cycle the clearance between open contacts did not reach the maximum, electric arc not fully burning then enter the closed state. Through two cycles, the mechanical work injects energy into mechanical system and makes it get store energy accumulation. The moving iron core movement amplitude increase, causing the electromagnetic force and mechanical work which electromagnetic force do gradually increases, the moving iron core displacement amplitude increase which will make the whole system stored potential energy and the convertible kinetic energy gradually increases, until the single cycle the mechanical work of which electromagnetic force do equal damping energy dissipation, so as to achieve stable process of reciprocating vibration, the displacement amplitude of moving iron core is constant, potential energy and convertible kinetic energy of storage system keep conservation, the mechanical work input and output of the sound energy is constant. Fig.6 is the transformation function relation of electromagnetic horn in transition.

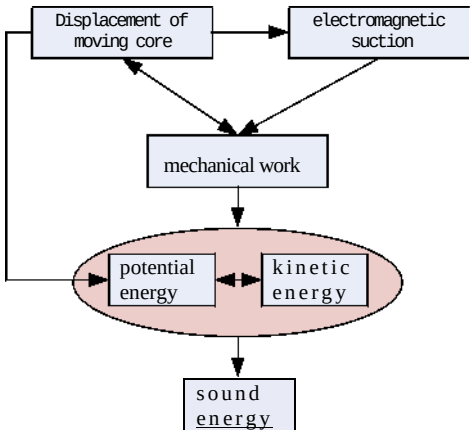


Fig. 6. the conversion relationship between work and energy during transition phase

4 Conclusions

In this paper, according to the principle of electromechanical energy conversion, studied energy conversion relations of vehicle horn from the touches to the steady reciprocating vibration state, laying a foundation for optimization design of the electromagnetic horn.

Using the dynamic change rule of performance parameters through the simulation analysis as the foundation, analysis the dynamic matching relations between the electromagnetic suction and mechanical reaction force, fully analyzed physical process of the electromagnetic horn from touches to steady reciprocating vibration .

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