Bull. ERS, No.15 (1982)

MALFUNCTION OF EDI-CURRENT TYPE RELAY UNDER SOME EARTHQUAKE CONDITIONS

by

Heki SHIBATA,I) Masakatsu INAGAKIII) and Takafumi FUJITAIII)

INTRODUCTION

Occasionally, malfunctions of edi-current type relays using for over-current protection of AC circuit were reported. It was reported by newspapers the event of loss of the power supply from the diesel power plant to the one third area of the island in the case of Hachijô-jima Earthquake of February 1972. Twenty-nine such events had been reported1) for those five years, including the cases of Niigata Earthquake in 1964 and other earthquakes. The authors observed this phenomenon during a shaking test of a set of an emergency power supply system to conventional buildings as well as other testings.2) An over-current relay, whose type is widely used for a protector of ordinary size power supply systems, mostly 10 ∿1000 KW, was mounted on an ordinary box-type steel switching box. Under a resonating condition of the steel pannel, the rotor disc turned slowly towards the state of its malfunction. The authors tried to cause this phenomenon by shaking this type of relays alone, and they found that only two-dimentional horizontal motions could cause such phenomenon. In this short article, the authors want to explain the phenomenon, and their simplified dynamic model briefly.

MECHANISM AND BEHAVIOR OF THE RELAY

Shematic drawings of the relay are shown in Figs.1 and 2. The disc is driven by electro-magnetic force given by the magnetic flux caused by the magnet (A) in Fig.2. The alternative magnetic flux causes edi-current flow in the disc (B) of the relay, and the excess current gives a torque on the disc so as to close the contact point (C) against the counter torque of a spring (D) for alarming the over-current. The mechanism is quite similar to a wattmeter widely used in houses.

A typical type of the over-current relay was mounted on a small three

---

I) Professor, III) Associate Professor, Institute of Industrial Science, University of Tokyo.
II) Former Graduate Student, University of Tokyo.

dimentional shaking table. This table is driven by three electro-magnetic shakers, and also it provides a pneumatic bellows for the balancing of gravity force. The size of the table is 28 × 28 cm.

The shaking test previously mentioned was done on a single axis shaking table, therefore the test of this time started in one directional shaking. However, the disc was standing still. The authors found that the two axial, circular motions only could cause the rotational response of the disc. The rotational movement was very much depending on the phase relation of two horizontal excitations. Slight difference of the frequencies of two excitations cause the go-and-return response of the disc according to the phase relation of two components, that is, the motion is linear or circular. The quantitative result will be described in the following section.

Here we put two axial motions in acceleration terms as follows:

$$\left.\begin{aligned} \ddot{x} &= \alpha \cos \omega t \\ \ddot{y} &= \beta \cos (\omega t + \Phi) \end{aligned}\right\} \qquad (1)$$

where Φ is the phase angle. And i in the figures is the normalized current giving the rotational torque, and $\theta_2 - \theta_1$ is the angle between the initial position and the contact point. The feature of the behavior is typically shown in Figs.3 and 4. In Fig.3 the critical acceleration of the malfunction can be shown the relation

$$\alpha\beta = \text{const.} \qquad (2)$$

and Fig.4 shown that the motive force for the malfunction is the strongest in the rectangular phase relation. That means the motive force (torque) standing on the vector product of $\ddot{x}$ and $\ddot{y}$, that is, the circular exciting motion is significant for the rotational response motion of the disc.

DYNAMIC MODEL OF RESPONSE BEHAVIOR OF DISC

This motive force (torque) of the rotational response of the disc comes form the supporting bearing whose structure is shown in Fig.5. As a mechanism of generating the torque on the disc, a whirl phenomenon of the shaft along the jewel edge can be considered. This phenomenon is an extreme non-linear one, and one of the authors has been studying its numerical model. Here, a simplified model is examined to find out what type of non-linearity causes a torque by two dimentional motions. If we can establish the following type non-linear equation,

$$\ddot{\theta} + 2\,\zeta\omega\dot{\theta} + \omega^2\theta = ki^2 + \varepsilon r^2 \frac{\dot{\phi}}{p} \qquad (3)$$

where r and ϕ are the variables of a polar co-ordinate of the excitation as shown in Fig.6. The second term of the left hand side of Eq.(3) as follows:

$$r^2 \frac{\dot{\phi}}{p} = \frac{1}{p}\left(\dot{Y}X - Y\dot{X} \right). \qquad (4)$$

where p is the circular frequency of the two-dimensional motions of the excitation. The area S of the elliptic motions is described as

$$\begin{aligned} S &= \Pi\alpha\beta \sin\Phi = \Pi r^2 \frac{\dot{\phi}}{p} \\ &= \frac{\Pi}{p}\left(\dot{Y}X - Y\dot{X} \right). \end{aligned} \qquad (5)$$

Therefore, if the torque to induce the rotation of the disc is proportional to the area of the excitation, then such phenomenon can be expected. The detail of a supporting bearing is as shown in Fig.7. By the external acceleration, a shaft moves to the point O_p, then the relation of acting points of force F_I and N becomes as a tri-angular in Fig.7. And we assume that this force couple cause the torque, and F_I and N is proportional to the amount of off-center of the shaft, r, then the following relation can be obtained,

$$T_v = F_I\, e' = F_I\, e\, \Psi = F_I\, e \frac{\dot{\phi}}{p}, \qquad (6)$$

and e is also proportional to r, then

$$T_v \propto r^2 \frac{\dot{\phi}}{p}. \qquad (7)$$

This relation is satisfying the relation of Eq.(3). The relation of the off-center of the shaft, r, to the distance between the shaft position O_p and the contact point P is also simplified one under an assumption of the small motion of the shaft. One of the authors, Fujita, and Inoue already completed the more detailed analysis of the mechanism.

However, the authors like to mention that an algebraic nonlinearity such as " square " or " product " of the motions sometimes induces a slow response of the system. This is one of such phenomena, and Kitamori reported that the malfunction of a float-type senser of liquid surface induced the instability of the flow in a process subjected to shock motions.3)

Using some ground motions, the simulations are done as shown in Figs.

8 and 9. For the earthquake input motions, the relay is mounted on a flexible supporting rack. The angle of rotation seems to be small. However, under most of actual operating condition the electric current i is near to their trigger level, therefore, such small additional torque may cause the malfunction.

CONCLUDING REMARKS AND ACKNOWLEDGEMENT

Some algebraic nonlinearity of a mechanism may cause the drift under earthquake motions. In this example, two-dimentional motions only cause such a type of drift, disc rotation. It is very difficult to estimate such behavior without testing previously. All existing types of such relays may cause malfunction under seismic excitations.

The authors like to express their gratitude to Mr. Koizumi, Mitsubishi Electric Co. for preparing the test speciments.

REFERENCES (in Japanese)

(1) Bureau of Public Works, Ministry of International Trade and Industries: Earthquake Resistant Characteristics of Electric Power Supply System (1970), p. 75.

(2) H. Yashima: Seismic Qualification Test of Electrical Equipment for Nuclear Power Plants, *Technical Report of Mitsubishi Electric Co.*, Vol. 48, No. 3 (1974), p. 351.

(3) T. Kitamori: On Mechanism of Malfunction of Senser and Instrumentation System due to External Vibration, *Report for the Technical Committee RC-SC 53 of JSME*, (1979).

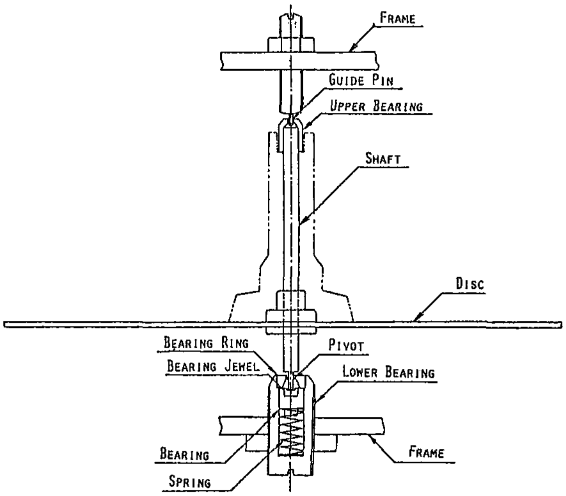

FIG. 1

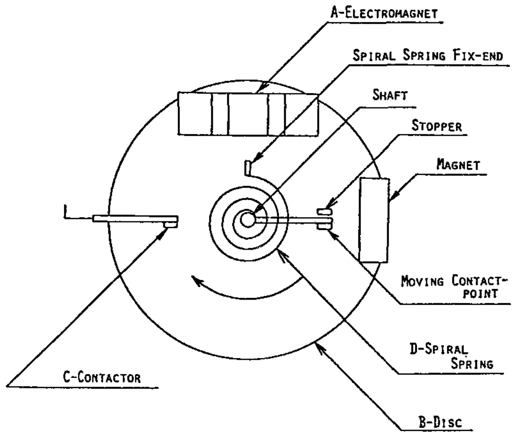

Fig. 2

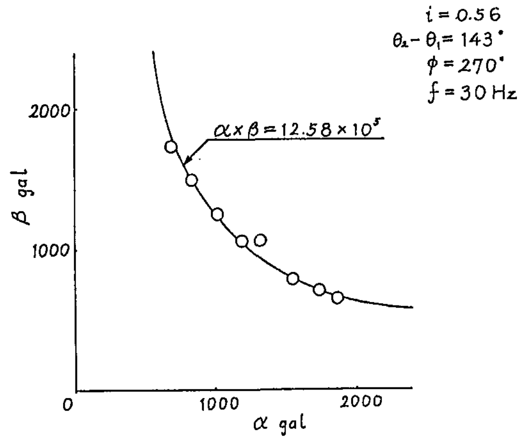

Fig. 3

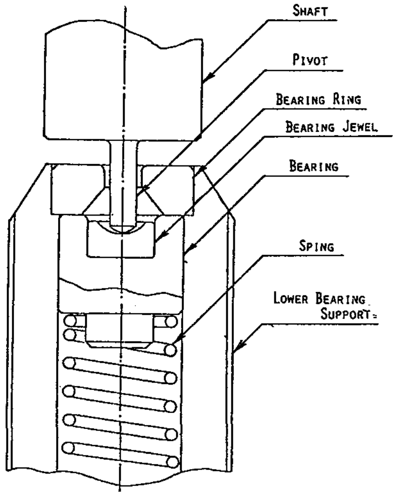

Fig. 5

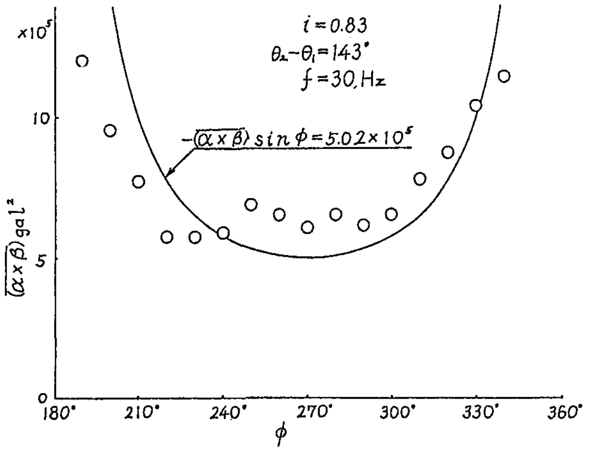

Fig. 4

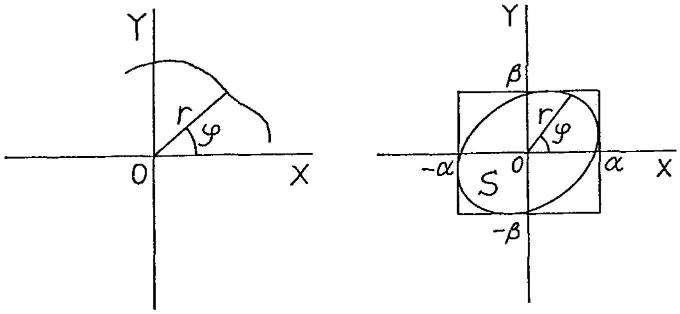

FIG. 6

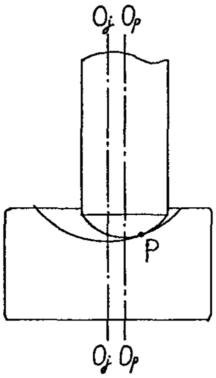

FIG. 7

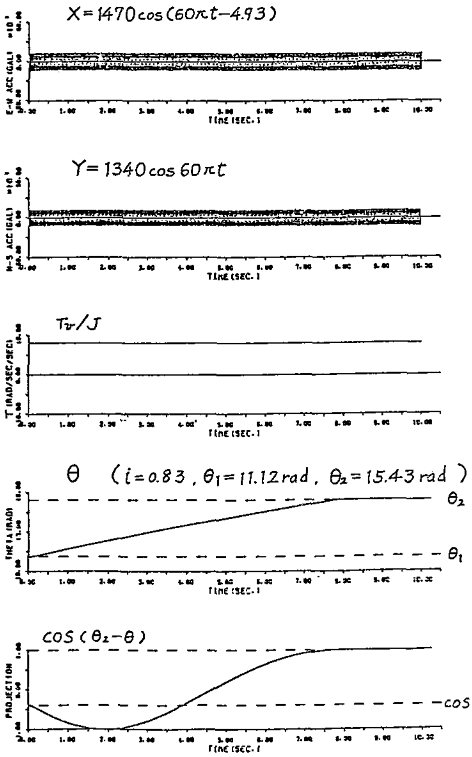

FIG. 8

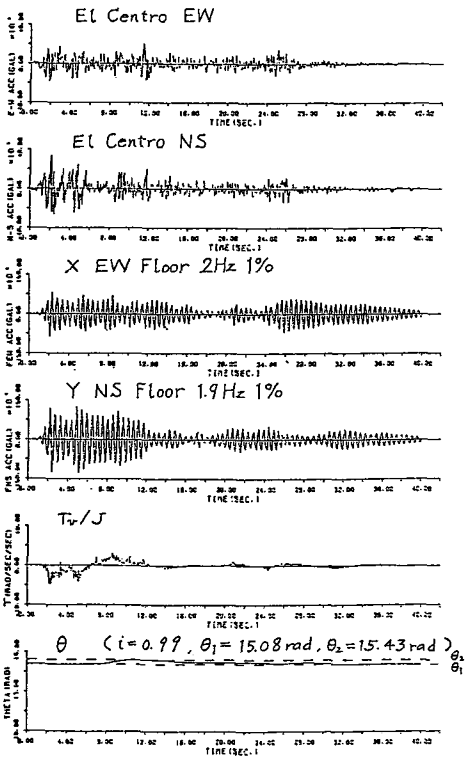

FIG. 9