Dynamic Analysis on the Closing Resistors of Gas Insulated Switchgear

Hae-Yong Cho*
Department of Mechanical Engineering, Chungbuk National University, San 48, Gaesin-Dong, Heungduk-Gu, Cheongju, Chungbuk 361-763, Korea
Sung-Ho Lee, Sung-Sam Lim
LS Industrial Systems Co., Ltd., Songjung-Dong, Heungduk-Gu, Cheongju, Chungbuk 361-720, Korea

GIS (Gas Insulated Switchgear) is used in electric power system to insure non conductivity, breaking capacity and operating reliability. In the present study, dynamic analysis on the closing resistors of the GIS has bees carried out by the commercial dynamic analysis code COSMOS MOTION and 3-D modeling program SOLID WORKS. In order to find the minimum value of chatter vibration of closing resistors, the motion of moving and fixed resistor parts of closing resistors were simulated by varying the spring constant, the damping coefficient and the mass of moving and fixed resistor parts. The simulated results were compared with experimental results. The application of the results could reduce chatter vibration of closing resistors of the GIS. These data are also useful on the development of future model GIS with minimum chatter vibration for the determinations of the spring constant, the damping coefficient and mass of a moving part.

Key Words : Gas Insulated Switchgear, Dynamic Analysis, Chatter Vibration, Closing Resistors

1. Introduction

The gas insulated switchgear (GIS), which is filled with SF6 insulating gas in the closed metallic pressure vessel, consists of circuit breaker, current transformer, disconn- ecting switch, and earthing switch. The GIS system is widely applied to the electric power system because of its excellent breaking and closing capabilities. GIS system ensures the security of the electric power system by closing abnormal current during the operation. After the breaking operation the GIS system has to return to the normal position for the normal operation of the electric power system. During the opening and closing operation the GIS system may have input surge due to chatter vibration of the closing resistor and the input surge makes the system unstable. In order to reduce the surge due to re-closing of circuit breaker and to get stability of the system, the input surge is suppressed by application of additional resistor that has identical phase with the circuit breaker.

Closing resistors are generally attached to the circuit breaker either internally or externally, and are classified into two types by the operation mechanism : the resistor has identical operating mechanism with the circuit breaker, and that has independent operation mechanism. The closing resistor may be inserted into the circuit breaker by tulip type contact or butt contact. The closing resistor with butt contact consists of the moving part that has opening and closing movements, and

* Corresponding Author,
E-mail : hycho@chungbuk.ac.kr
TEL : +82-43-261-2464; **FAX** : +82-43-263-2448
Department of Mechanical Engineering, Chungbuk National University, San 48, Gaesin-Dong, Heungduk-Gu, Cheongju, Chungbuk 361-763, Korea. (Manuscript **Received** February 1, 2006; **Revised** July 18, 2006)

the fixed resistor part. The fixed resistor part are composed of the spring that absorbs the impact energy originated from the moving part, the case that envelopes the spring, and the resistor for the reduction of surge. If chatter vibration occurs at the spring during the operation, the fixed resistor can not reduce the surge at the closing resistor.

Many attempts have been paid to improve stability of GIS system. Chen (2003) analyzed operation characteristics of spring type mechanism on the SF6 gas circuit breaker. Lee (2003) studied signal characteristics of resonance frequency of SF6 gas. Lee (1998) developed butt type single contact GIS of 362 kV grade. Impact stress of circuit breaker has been analyzed with finite element method by Kim (1999). Ochiai (2002) developed single contact 550 kV grade repairable circuit breaker with high reliability. Ahn (2004) studied optimal design of spring used in breaker. Legate (1998) studied on EVH circuit breaker without closing resistor. Kim (2004) studied inexpensive circuit breaker with closing resistor-free for the sort distance electric power transmission. Most of the studies were confined to structural analysis and operating mechanism of the circuit breaker, however, a few reports on the surge with the closing resistor.

The present study has been carried out to reduce the electrical surge caused by the chatter vibration due to collision of the fixed resistor part and moving part of the butt contact circuit breaker. Analyses on the spring constants of moving part and fixed resistor part, damping coefficient, gravity of moving part of the resistor have been carried out in conjunction with experiments on the dynamic characteristics.

2. Dynamic Analysis

The behavior of the moving part and fixed resistor part of the closing resistor during collision of these two parts has been carried out through COSMOS MOTION (Solid Works Corporation) which is a commercial software for the dynamic characteristic analysis. For dynamic analysis of closing resistor, solution of constitutive equations is constructed by

$$x(t) = C_1 e^{s_1 t} + C_2 e^{s_2 t} = C_1 e^{\left\{\frac{c}{2m} + \sqrt{\left(\frac{c}{2m}\right)^2 - \frac{k}{m}}\right\}t} + C_2 e^{\left\{\frac{c}{2m} + \sqrt{\left(\frac{c}{2m}\right)^2 - \frac{k}{m}}\right\}t} \quad (1)$$

here m is mass, c is damping coefficient, k is spring constant and c_1, c_2 are optional constants from initial conditions.

The behavior of solution is depended upon dimensions of damping. Critical damping constant, c_c is defined by damping constant, c. The relation of c_c and c is expressed by

$$\zeta = \frac{c}{c_c} \quad (2)$$

here ζ is damping ratio.

In case of under damped system, the solution at condition of $\zeta < 1$, $c < c_c$ becomes

$$x(t) = e^{-\zeta\omega_n t}\left\{x_0 \cos\sqrt{1-\zeta^2}\,\omega_n t + \frac{\dot{x}_0 + \zeta\omega_n x_0}{\sqrt{1-\zeta^2}\,\omega_n}\sin\sqrt{1-\zeta^2}\,\omega_n t\right\} \quad (3)$$

In case of critically damped system, the solution at condition of $\zeta = 1$, $c = c_c$ becomes.

For collision analysis of closing resistor, the analysis is made of converting impact load of the collision to static load. The Value of impact factor, $(1+\sqrt{1+2h/\delta_{st}})$ multiplied by static load, P is used for the analysis.

Various values of the spring constant, damping coefficient and weight of each part have been applied for the analysis to reduce chatter vibration. The analysis has been carried out with the initial condition that the moving part collide to the fixed resistor part with the speed of 9.8 m/s under the assumption of rigid body of the moving part and the fixed resistor part.

Analyses were carried out successively for each case as shown in Fig. 1. The damping coefficients were 0.6 N-s/mm for the fixed resistor part, and 5 N-s/mm for the moving part respectively. The input data were changed for each spring constant in the analysis.

Damping coefficients were varied as same as spring constant 0.5 N-s/mm, 0.6 N-s/mm for the fixed resistor part, and 0.05 N-s/mm, 0.1 N-s/mm, 0.5 N-s/mm, 1 N-s/mm, 2 N-s/mm, 5 N-s/mm for the moving part.

Weight values of the moving part for the analysis were 3.31 kg, 3.41 kg, 3.60kg, 3.69 kg, 3.86 kg,

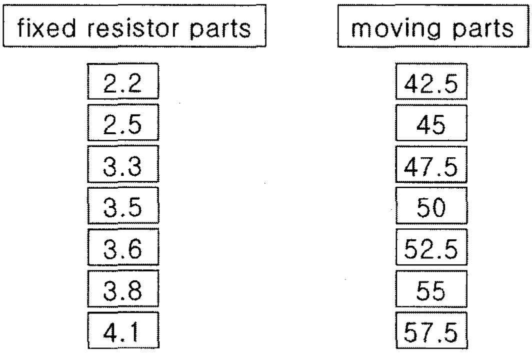
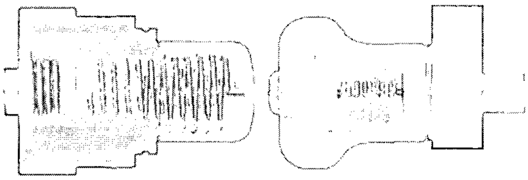


Fig. 1 Procedure of analysis for various spring constant (N/mm) of moving and fixed resistor parts



(a) Fixed resistor part (b) Moving part

Fig. 2 3-D Modeling of closing resister for 362 kV Gas insulated switchgear

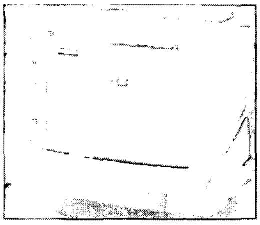
4.14 kg, 4.23 kg, 4.42 kg. The spring constant and damping coefficient were 3.1 N/mm, 0.6 N-s/mm for the fixed resistor part and 50 N/mm, 5 N-s/mm for the moving part respectively during the analysis.

The analysis was carried out the dynamic characteristics of 362 kV grade circuit breaker. 3 dimensional modelling through SOLIDWORKS on the circuit breaker is displayed in Fig. 2. Modelling for the fixed resistor part and the moving part are shown in Fig. 2(a) and (b) respectively. The material for the moving part and fixed resistor part is stainless steel 400 whose Young's modulus is 200 GPa and Poissson's ratio is 0.26. Yield strength and tensile strength of the material are 200-230 MPa and 400-450 MPa.

3. Experiments

The actual GIS was used for the experiments on dynamic analysis of the moving part and the fixed resistor part as shown in Fig. 3. High speed camera (Motionxtra HG-LE), Image analyzer (Image Express Vision V5.5y), and system analysis software (PKE series Model) were used for the analysis as shown in Fig. 4.

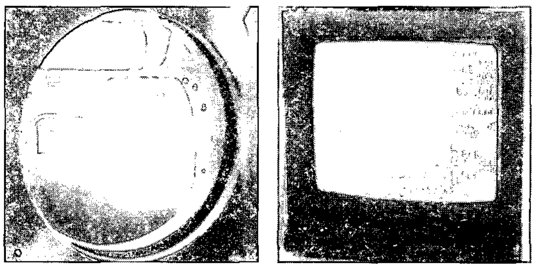
Fig. 3 Gas insulated switchgear



(a) Image analyzer

(b) System analyzer (c) High speed camera

Fig. 4 Data acquisition and analyzer systems



(a) Attached point at fixed resistor part (b) Pictures by high speed camera

Fig. 5 Data acquisition by using high speed camera

High speed photographs were taken on the circular indications attached to the moving part and fixed resistor part during the operation of the GIS as shown in Fig. 5. The position of the circular indications on the taken photos were measured with image analyzer. The movement of the circular indications was plotted in terms of collapsed time. The stability of the system was evaluated by system analyzer with the electrical signal during the collision on the moving part and the fixed resistor part.

4. Results and Discussions

4.1 Analysis with various spring constant

Dynamic analysis with various spring constants has been carried out as mentioned previously. The maximum distance between the two parts was found through the analysis result on the colliding position and the maximum displacement after the collision at each condition. Fig. 6 displays the dynamic analysis result for the condition that spring constant of the moving part is 42.5 N/mm and that of the fixed resistor part is 2.2 N/mm. The maximum displacement is measured instant amplitude during chatter vibration, and the maximum displacement is the distance between the moving part and the fixed resistor part. The large amplitude during the collision of the two parts makes the large displacement, and the large displacement also makes the large distance between the two parts, which causes the system unstable due to short contact between the preliminary contact points. The maximum value at each condition was summarized in Table 1. Fig. 7 shows the maximum displacement values with various spring constants as listed in Table 1.

It was found through the dynamic analysis that the system is stable with spring constant of the fixed resistor part is in the range of 2.2~2.5 (N/mm), 3.8~4.1 (N/mm) and that of the moving part is in the range of 40~42.5 (N/mm), 57.5~60 (N/mm). However, the maximum displacement values have no relationship with the spring constants.

Independent operation of each spring at the moving part and the fixed resistor part, and resonance

Table 1 Simulated maximum displacements between moving and fixed resistor parts with various spring constants (mm)

fixed resistor parts \ moving parts	42.5 (N/mm)	45 (N/mm)	47.5 (N/mm)	50 (N/mm)	52.5 (N/mm)	55 (N/mm)	57.5 (N/mm)
2.2 (N/mm)	4.2	4.6	4.2	4.3	4.6	4.1	4.5
2.5 (N/mm)	4.1	4.0	4.0	4.0	4.1	4.0	4.4
3.3 (N/mm)	3.8	3.8	3.9	4.0	3.7	4.3	3.8
3.5 (N/mm)	3.8	3.9	4.1	3.7	3.8	3.7	3.7
3.6 (N/mm)	3.7	3.6	3.8	3.7	3.8	3.6	3.8
3.8 (N/mm)	3.8	3.6	3.7	3.7	4.1	3.6	4.1
4.1 (N/mm)	3.6	3.6	3.7	3.7	3.7	4.1	3.6

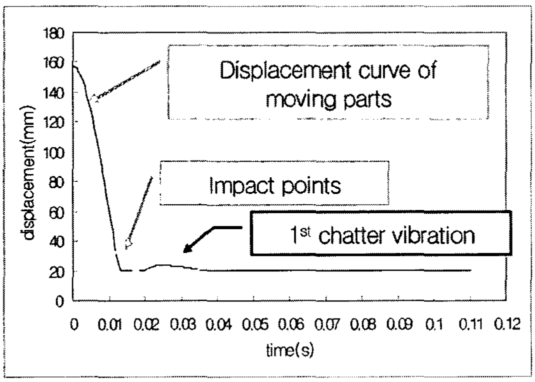


Fig. 6 Displacement curve of moving part (Spring constant : moving parts 42.5 (N/mm), fixed resistor parts 2.2 (N/mm))

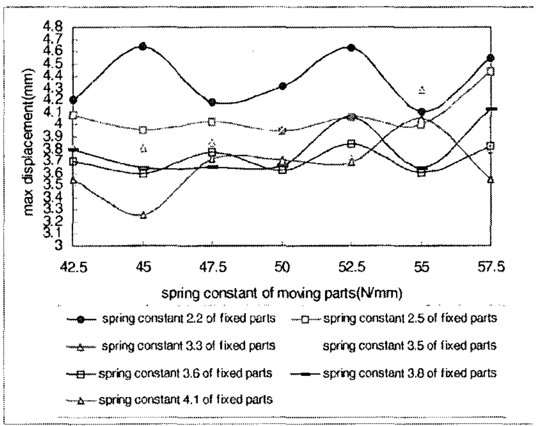


Fig. 7 Simulated maximum displacements between the moving and the fixed resistor parts with various spring constants

and interference of the two springs during collision might cause the irregular behaviour. The resonance and the interference increased the impact energy, which caused irregular value in the dynamic analysis. The present dynamic analysis try to find optimum condition to reduce chatter vibration rather than the regularity, therefore, the maximum distance between the two parts, time interval among the contacts have been considered.

4.2 Dynamic analysis with various damping coefficient

Dynamic analysis with various damping coefficient of the two parts is shown in Fig. 8. It was found that the maximum distance between the two parts reduced with increasing the damping coefficient of the fixed resistor part. The reduced the chatter vibration due to the increased the damping coefficient of the fixed resistor part made the system stable because high absorption rate of impact energy during the collision of the two parts returned the system stable instantly. The whole GIS system becomes stable with increment of the damping coefficient of the fixed resistor part, however, the maximum displacement increased with the increment of the damping coefficient of the moving part. It is worth to remind that the phenomenon occurred not only on the moving part but also on the fixed resistor part.

Therefore, it is desirable to avoid the value of damping coefficient that increases chatter vibration in the design of the GIS system. The analysis result indicates that the damping coefficient of the fixed resistor part reduced the chatter vibration more than that of the moving part. The appropriate damping coefficient of the moving part was found to be in the range of 0.5~2 N-s/mm.

4.3 Dynamic analysis with various mass of moving part

Dynamic analysis with various impact energy has been carried out, because collision energy may affect chatter vibration. The simulated results displays optimum displacement at 3.8 kg, mass of the moving part as shown in Fig. 9. It shows that mass of the moving part should be kept with 3.8 kg in design of the part. The analysis indicates that the maximum total mass for the stable system is 4.1 kg, and the minimum value is about 3.4 kg.

4.4 Experimental results

The experimental results are shown in Figs. 10 and 11, system stability was estimated with photographs by high speed camera and analysed by system analyzer.

The results shown in Fig. 10 is similar to that in Fig. 6. The two parts moves 100 mm to the fixed resistor parts after impact, and then the two parts were stopped and the chatter vibration occurred by impact energy at the stopped point of the two parts. The maximum displacement of moving part and fixed resistor part when chatter vibration occurs was very similar to that of analy-

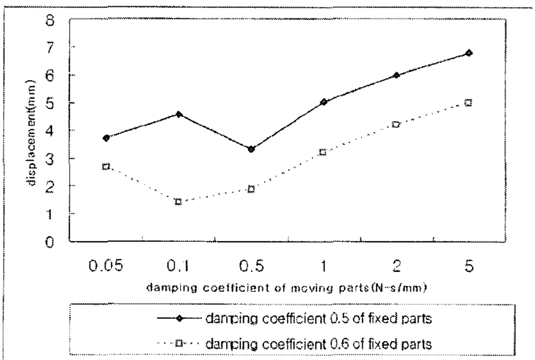


Fig. 8 Simulated results varying damping coefficient

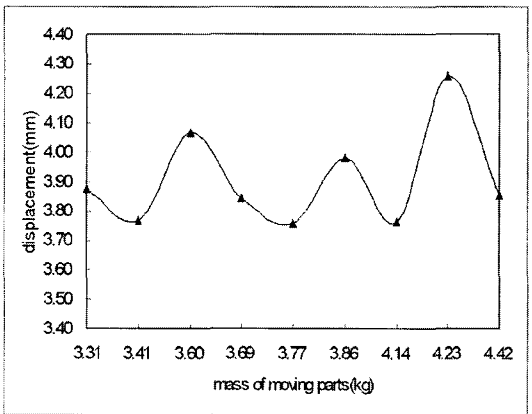


Fig. 9 Simulated maximum displacements between moving and fixed resistor parts by varying mass of moving part

sis. Experimental results were analysed by system analyzer.

Figure 11 shows experimental results with system analyzer at which the electrical signals during the collision of the moving part and the fixed resistor part indicate the appearance of the first and the second chatter vibration. The interesting point in the present study is the first chatter vibration, which is chatter vibration by the collision between the two part. As shown in the experimental results chatter vibration continues for about 7 ms that is actual colliding time. The electric condition during the collision has kept almost constant amplitude and vibrating wavelength.

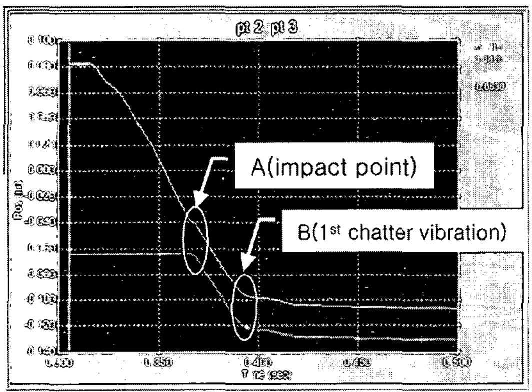


Fig. 10 Displacement of moving and fixed resistor parts by high speed camera (Spring constant moving parts 42.5 (N/mm), fixed resistor parts 2.2 (N/mm))

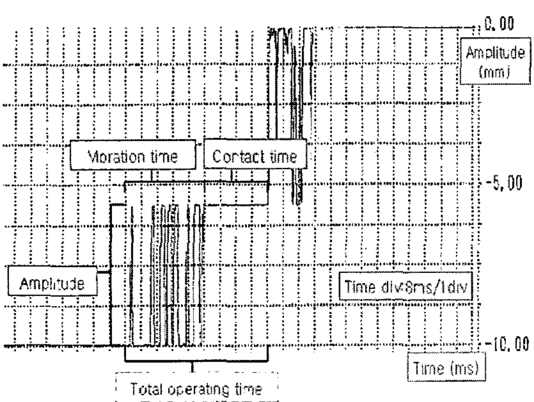


Fig. 11 Experimental results by using system analyzer

From the result it was identified that the unstability of the system due to chatter vibration could be reduced.

5. Conclusions

In the present study, the conclusions through the dynamic analysis on the closing resistor of the GIS system by COSMOS Motion and experiment with the actual component are as follows :

(1) The range of spring constant to minimize chatter vibration and surge of the system has been found. It was found through the dynamic analysis that the system is stable with spring constant of the fixed resistor part is in the range of 2.2~2.5 (N/mm), 3.8~4.1 (N/mm) and that of the moving part is in the range of 40~42.5 (N/mm), 57.5~60 (N/mm)

(2) The chatter vibration was reduced with high damping coefficient of the fixed resistor part and the moving part in dynamic analysis. However, time for stabilizing the system after the collision between the fixed resistor part and the moving part of the resistor was long with the high damping coefficient.

(3) It is desirable that the maximum total mass for the stable system is 4.1 kg, and the minimum value is 3.4 kg.

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