13th World Conference on Earthquake Engineering
Vancouver, B.C., Canada
August 1-6, 2004
Paper No. 314

EXPERIMENTAL AND ANALYTICAL STUDY OF LEAD ALLOY ABSORBER FOR ELECTRICAL EQUIPMENTS WITH PORCELAIN BUSHINGS

Yaqi LI[1], Xiaojun LI[2]

SUMMARY

Firstly, this paper presents damping effect of a new kind of absorber, named lead alloy absorber, through experimental study of a typical circuit breaker isolated with lead alloy absorbers. The experimental study shows that the reduction ratio is about 0.7. Secondly, a finite element modal is found based on the experimental data for further analysis. The damping effect is evaluated under some special ground motions which can not be realized by vibration table, such as ground motions with significant long period contents and ground motions with velocity-pulse. For these cases, the damping effects are not clear at all.

1. INTRODUCTION

Electrical equipment with porcelain bushings which can be easily damaged in earthquake is one of the most important components in transformer substations or power plants. The main reasons of being damaged include that [1]:
(1) porcelain bushings can not resist large bending moment and displacement because porcelain is a kind of brittle material;
(2) it is easy for this kind of equipments whose natural frequency is close to earthquake motions to resonate with earthquake motion;
(3) the damping rate of this kind of equipments is so small that equipment can deplete little earthquake energy.
Therefore changing the dynamic behavior of equipment is an efficient method to improve earthquake resistant capability. It is a good idea of using absorbers and dampers to change the natural frequency and damping ratio of equipments. In China, robber bearing widely used in buildings is employed as damper of electrical equipments. However, aging and large displacement etc. are great disadvantages for this kind of damper. Lead Alloy Absorber is developed to solve these questions, and it has been used as absorber of 500kV isolating switches in Tianjin Panshan Power Plant.
Lead Alloy Absorber develops so late that it does not suffer actual earthquakes, and a little has been done to improve damping effect of this kind of absorber. In this paper damping effect of the absorber is analyzed by shake table test and finite element calculation.

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[1] Institute of Geophysics, China Earthquake Administration Email: lily0698@sina.com
[2] Institute of Geophysics, China Earthquake Administration

2. SHAKE TABLE TEST

LW11-252/Q SF_6 Circuit Breaker employed as testing equipment is produced by Beijing Beikai electrical Corporation. Figure 1 shows the configuration of the circuit breaker. The whole equipment is formed by three parts: porcelain bushings, supporting frame and gas tank. Figure 2 shows the Lead Alloy Absorber also used as testing absorber.

Figure 1 Configuration of Circuit Breaker

Figure 2 Lead Alloy Absorber

2.1 Test design

1. White noise test

A white noise whose frequency covers 0.1~120Hz is applied as input motion to obtain natural behavior of the circuit breaker in this test.

2. Time history test

It is supposed to input artificial ground motions for origin scale test of electrical equipment with supporting frame [2]. Following this ruler, this test designs two artificial ground motions.

One of the required response spectrums of artificial motions is adopted design spectrum provided by <Code for design of seismic of electrical installation>. Figure 3 shows artificial motion named As according to the required response spectrum.

However the design spectrum provided by GB50260-96 is just a mean value and have not much to do with the test equipment. This test design a required response spectrum related to dynamic behavior of the equipment and ground motion attenuation relations on rock in Huabei area in China. According to the characteristic of the Circuit Breaker and other test results of electrical equipments, natural period of the circuit breaker is in the range of 0.1-0.4s at a rough estimated. So the main period of artificial motion should cover this range. Figure 4 shows the artificial ground motion called Aa.

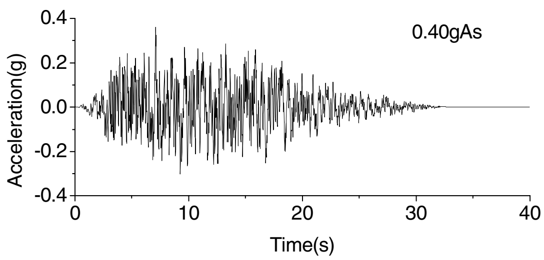


Figure 3 Artificial motion As

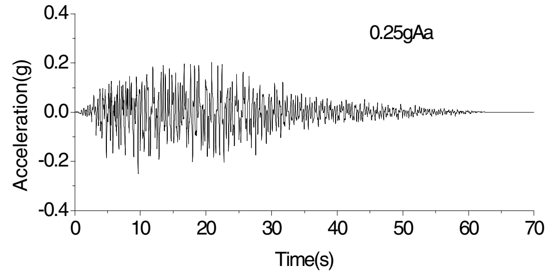


Figure 4 Artificial motion Aa

3. Test conditions

Four Lead Alloy Absorbers are fixed at the joint of bushing and supporting frame of LW11-252/Q SF_6 Circuit Breaker. There are two conditions in this test, viz. test of equipment without absorbers and test of equipment with absorbers, to analyze the absorbers' damping effect. In this paper the former is named Condition 1 (C1), and the latter is named Condition 2 (C2).

2.2 test points' layout

Accelerotransducers and strain gauges are employed as recording apparatus in this test. The principles of placing test points include:

1. placing accelerotransducer on the top of the shake table to record actual inputting motions;
2. placing several accelerotransducers along the circuit breaker to get the mode of the equipment;
3. placing accelerotransducer on the top of the porcelain bushing to get response of the whole equipment;
4. placing strain gauges at the foot of porcelain bushing.

Figure 7 shows the layout of test points.

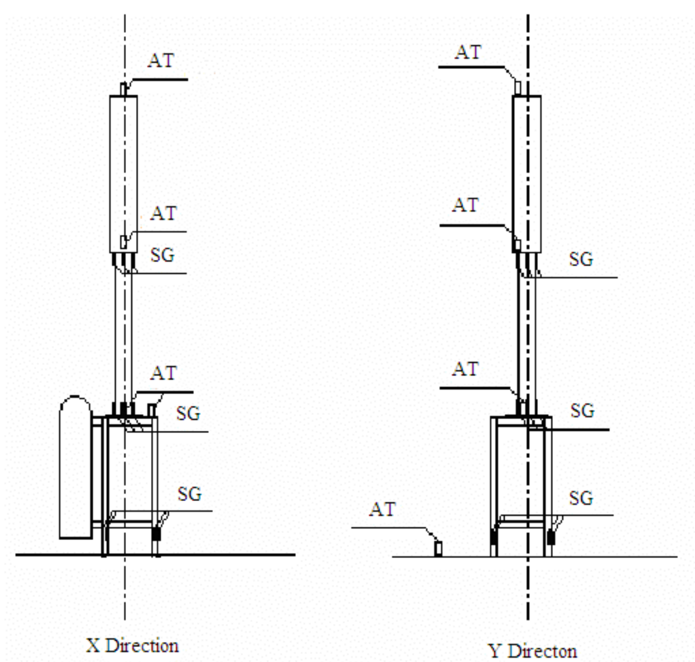


Figure 5 layout of test points (AT: accelerotransducers, SG: strain gauges)

2.3 Data analysis

In this part the dynamic amplification factor of the equipment and the damping effect of the absorber are analyzed. The dynamic amplification factor means the ratio of the amplitude of acceleration time history on the top of the bushing and the amplitude of acceleration time history on the top of vibration table. The stain reduction ratio (the ratio of the maximum stain of the bushing of the two models) is defined as the damping effect, because the maximum strain of the bushing controls earthquake damage of the circuit breaker. Table 1 shows the main results. Under two artificial motions, the amplification factor is reduced 10% in the X direction and 15% in the Y direction, and strain response at the foot of the bushing is reduced 23% in the X direction and 33% in the Y direction after installing absorbers.

Tab1e 1 （a） The amplification factor of the Circuit Breaker under artificial motions

Direction	items	As（0.25g）		Aa（0.25g）		As（0.40g）		Aa（0.40g）	
		C1	C2	C1	C2	C1	C2	C1	C2
X	α_0	0.21	0.23	0.20	0.25	0.38	0.39	0.42	0.41
	α_1	1.00	1.04	1.38	1.33	1.81	2.20	2.46	2.40
	Af	4.8	4.5	6.9	5.2	4.8	5.7	5.9	5.9
Y	α_0	0.23	0.24	0.22	0.23	0.41	0.43	0.42	0.46
	α_1	1.02	0.91	1.34	1.20	1.58	1.56	2.41	1.90
	Af	4.5	3.8	5.6	5.2	3.9	3.6	5.7	4.1

Where

α_0= the amplitude of acceleration time history on the top of vibration table.

α_1= the amplitude of acceleration time history on the top of the bushing.

Af= amplification factor.

Table 1（b） the damping effect of the Circuit Breaker under artificial motions

Direction	Strain at the foot of bushing	As（0.25g）		Aa（0.25g）		As（0.40g）		Aa（0.40g）	
		C1	C2	C1	C2	C1	C2	C1	C2
X	ε（μ）	105	86	145	119	194	177	254	196
	Damping effect	25％		34％		12％		21％	
Y	ε（μ）	105	75	134	90	165	136	260	140
	Damping effect	32％		30％		20％		51％	

Where

ε=strain at the foot of bushing.

3 FINITE ELEMENT MODEL

3.1 finite element model

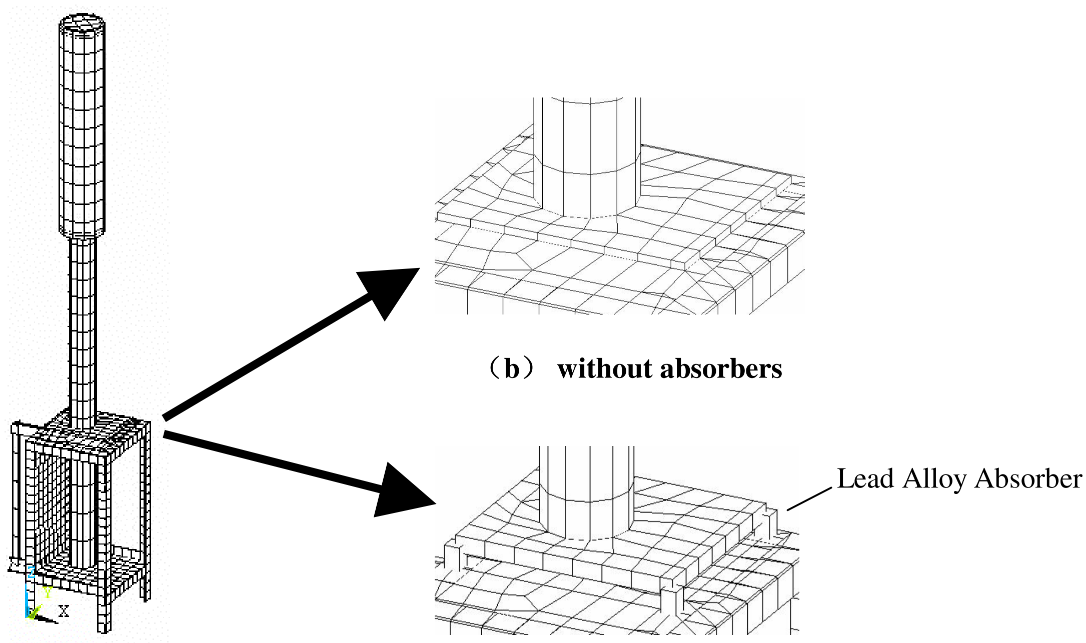
The weight of gas tank is so large that the movement of the equipment will include twist movement even under single direction ground motions, so it is not enough to form planar model. Three-dimensional finite element model is applied to simulate the circuit breaker.

(1) Equipment model

Three-dimensional block elements are employed to model bushings and three-dimensional beam elements are employed to model supporting frame and gas tank. The whole model of the circuit breaker consists of a total of 1409 nodes and 972 elements as shown in Figure 6 (a).

(2) Lead Alloy Absorber model

Lead Alloy Absorber is made of lead and a little other kind of metals. The deformation of the absorber displays tension deformation and compression deformation according to the structure of the absorber. The hysteretic behavior of the RLP56A Lead Alloy Absorber is shown in Figure 7. It can be seen that the hysteretic curve displays typical elasto-plastic mental behavior, so bi-linear plastic bar element is used to model the absorber in this paper.



（b） without absorbers

（c）installing absorbers

（a） equipment model

Figure 6 Finite element model of LW11-252/Q SF_6 Circuit Beaker

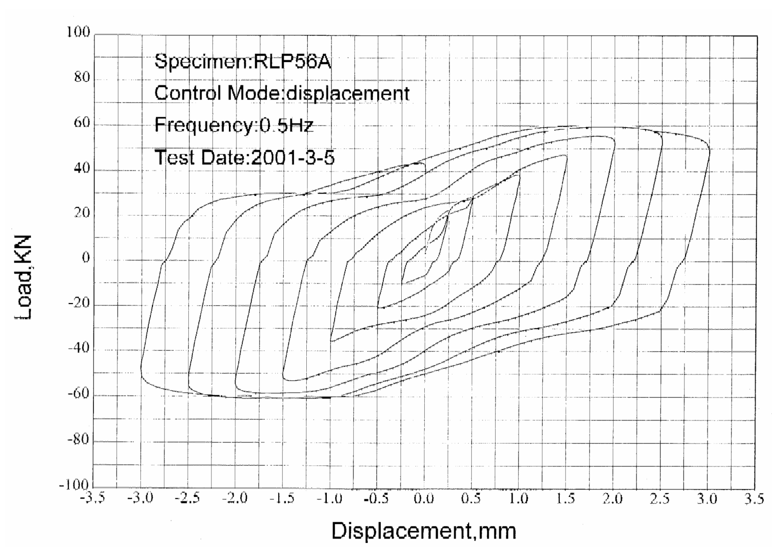


Figure 7 Hysteretic behavior of the Lead Alloy Absorber

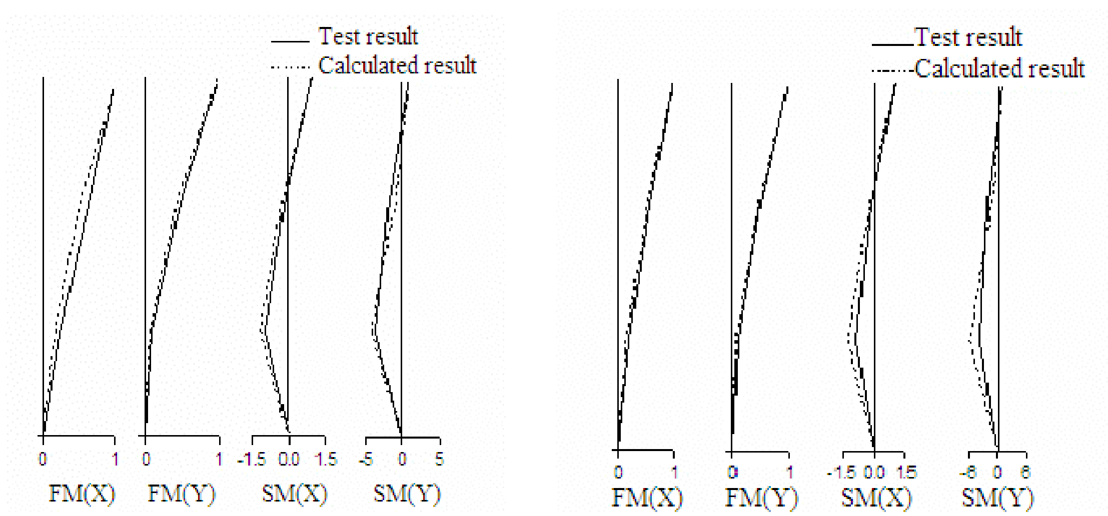
3.2 Comparing test results with finite element results

(1) Modal results

Table 2 and Figure 8 show the test results and finite element calculated results of both conditions. It can be seen that two kind of results are similar, especially the results of first-order modal.

Table 2 Comparing of tested to calculated natural frequency of equipment

Condition	direction	Frequency of first mode（Hz）		Frequency of second mode（Hz）	
		Test result	Calculated result	Test result	Calculated result
C1	X	4.0	4.0	8.7	8.4
	Y	4.4	4.4	11.7	13.0
C2	X	3.8	3.8	8.2	7.2
	Y	4.2	4.1	11.3	12.3



(a) Without absorbers (b) With absorbers

Figure 8 Comparing test results to calculated results of fore-and-aft installed absorbers
FM: First mode. SM: Second mode

(2) Time history results

The test results and calculated results of both acceleration time history on the top of bushing and stain time history at the foot of bushing are compared to know whether the finite element model is reasonable or not. Table 3 shows the amplitude of acceleration time history on the top of bushing and the amplitude of stain time history at the foot of bushing.

Table 3 Comparing test result to calculated result of the amplitude of acceleration time history on the top of bushing and the amplitude of stain time history at the foot of bushing.

Condition	Direction	Artificial ground motion	Amplitude of acceleration time history on the top of bushing （g）		amplitude of stain time history at the foot of bushing（μ）	
			Test results	Calculated results	Test results	Calculated results
C1	X	0.25gAs	1.00	0.74	103	101
C1	X	0.25gAa	1.38	1.38	144	122
C1	X	0.40gAs	1.82	1.42	191	211
C1	X	0.40gAa	2.46	1.87	246	244
C1	Y	0.25gAs	1.02	0.84	90	104
C1	Y	0.25gAa	1.34	0.95	130	121
C1	Y	0.40gAs	1.59	1.63	158	196
C1	Y	0.40gAa	2.41	1.74	241	225
C2	X	0.25gAs	1.04	0.77	84	102
C2	X	0.25gAa	1.33	0.93	119	106
C2	X	0.40gAs	2.20	1.32	176	165
C2	X	0.40gAa	2.40	1.58	191	170
C2	Y	0.25gAs	0.91	0.70	75	90
C2	Y	0.25gAa	1.20	0.75	89	99
C2	Y	0.40gAs	1.56	1.98	134	130
C2	Y	0.40gAa	1.90	1.05	139	134

There are several reasons bringing on discrepancy:

1. Rayleigh damp adopted as calculating damp did not accord with actual damp of equipment;
2. Supporting frame may display nonlinear behavior in test, but only absorber’s nonlinear behavior is included in finite element model;
3. Some uncontrolled factors may affect test result data.

As a whole, calculated results are close to test results, so the finite element model can be applied further.

4 DAMPING EFFECT OF THE ABSORBER UNDER SPECIAL GROUND MOTIONS

4.1 Ground motions with significant long-period contents

There are many ground motions with significant long-period contents in actual earthquakes, such as Mexico earthquake (1985) and Chi-Chi earthquake (1999); all of them bring huge economic loss and casualty. So it is necessary to discuss the damping effect of Lead Alloy Absorber under this kind of ground motions. Two artificial motions are designed, one of them named AL1 shown in Figure 9 is defined by a spectrum (also shown in Figure 9) under earthquake environment of magnitude of 8.0 and epicentral distance of 107km, the other named AL2 shown in Figure 10 is defined by a spectrum (also shown in Figure 10) under earthquake environment of magnitude of 8.5 and epicentral distance of 113km.

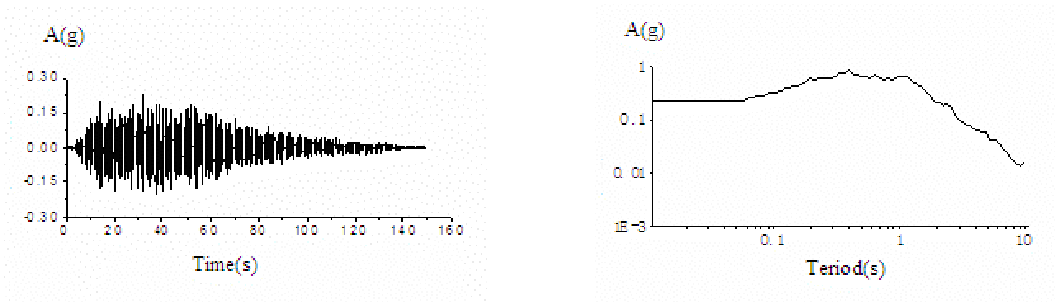


Figure 9 Acceleration time history and spectrum of ground motion AL1

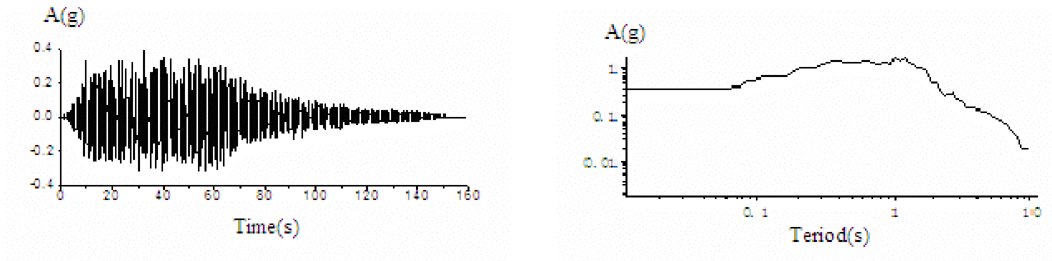
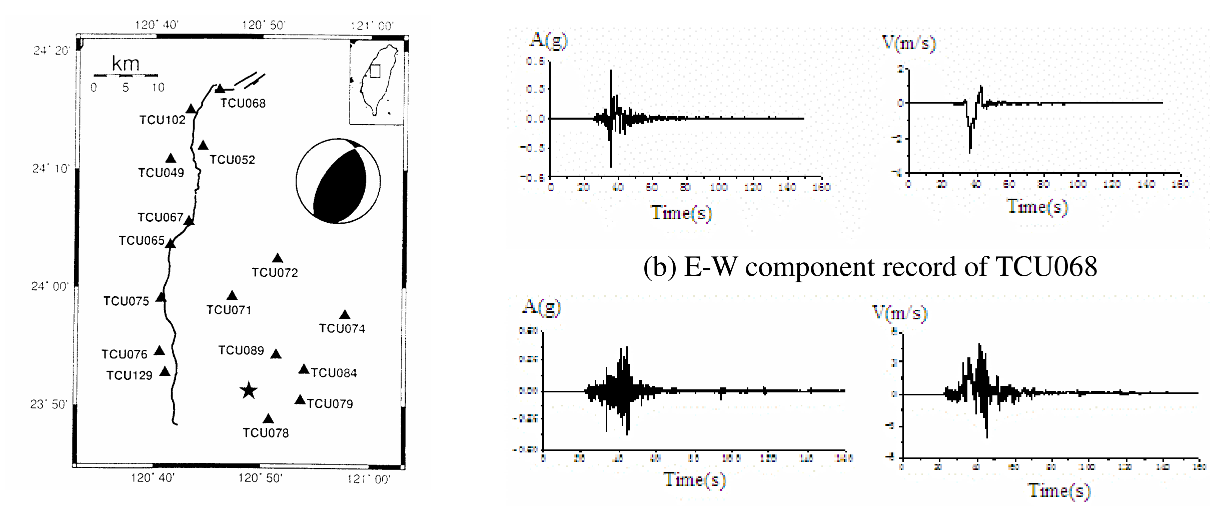


Figure 10 Acceleration time history and spectrum of ground motion AL2

4.2 Near field ground motions with velocity-pulse

In recent years, following city's expansion, the ratio of near field earthquake is more and more large; the earthquake damage is more and more serious. Northridge Earthquake (1994) in America and South Binko Earthquake (1995) in Japan brought huge losses belong to this situation. Some researches indicate that structures' response under near field ground motions with velocity-pulse is significantly different to other kind of ground motions. So records of Chi-Chi Earthquake are selected to analyses damping effect of Lead Alloy Absorber in this paper.

Figure 11 shows stations near the Chi-Chi Earthquake Fault. East-west direction ground motion with velocity-pulse of TCU068 and TCU074 are employed as input.



(b) E-W component record of TCU068

(a) Stations near the Chi-Chi Earthquake Fault (c) E-W component record of TCU074

Figure 11 Near field ground motions with velocity-pulse

4.3 Calculated results

From the acceleration response on the top of bushing and the strain response at the foot of bushing as shown in table 3 it can been seen that the damping effect is not obvious. The damping principles of the absorber are: using plastic distortion to consume input energy; changing the natural period of equipments.

The absorber will change the natural period of the whole system (equipment and absorbers), that will make the period away from the predominant period of ground motions with significant short-period contents but close to the predominant period of ground motions with significant long-period contents. There are two impacts acted on the equipment by absorbers under AL1 and AL2, reduced response by consuming energy and increased response by changing the natural period of equipment. So it is not notable of damping effect combining two impacts.

Under near field ground motions with velocity-pulse, the absorber not only does not reduced response of equipment but increase response of equipment in some conditions as shown in Table 4. Figure 13 shows the curves of internal force and deformation of absorbers under east-west direction record of TCU068. It can be seen that the deformation of the absorber is near to elastic deformation. In addition, in some cases the response of equipment will increase for the natural characteristic changed.

Table 4 Comparing response of equipment with absorbers to without absorbers

Input motion	Condition	Amplification of acceleration at the top of bushing（g）	Amplification of strain at the foot of bushing（μ）
AL1 (X)	C1	1.03	148
	C2	0.84	124
	DE	18.4%	16.2%
AL1 (Y)	C1	0.74	107
	C2	0.76	107
	DE	-2.7%	0%
AL2 (X)	C1	1.63	233
	C2	1.48	214
	DE	9.2%	8.2%
AL2 (Y)	C1	1.22	180
	C2	1.19	165
	DE	2.5%	8.3%
TCU 068 (X)	C1	1.47	208
	C2	1.37	204
	DE	6.8%	1.9%
TCU 068 (Y)	C1	1.20	173
	C2	1.24	175
	DE	-3.3%	-1.2%
TCU074 (X)	C1	1.24	149
	C2	1.28	152
	DE	-3.2%	-2.0%
TCU074 (Y)	C1	1.09	140
	C2	0.85	113
	DE	22.0%	19.3%

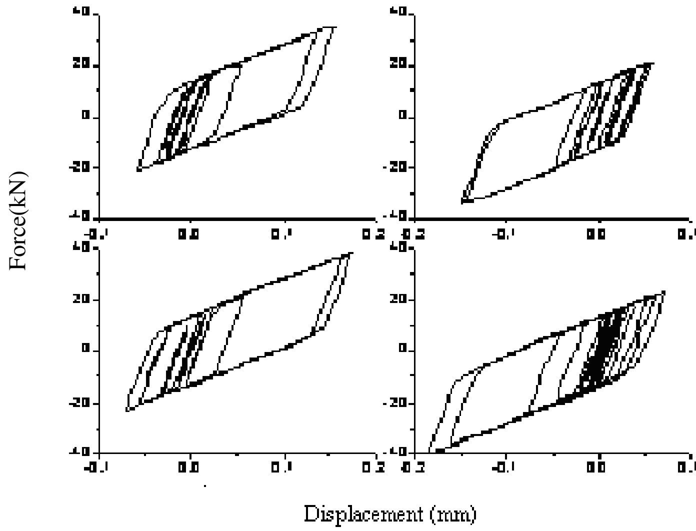


Figure 12 force-displacement curves of absorbers under TCU068E-W component

5 CONCLUSIONS

In this paper the damping effect of Lead Alloy Absorber applied to high-voltage electrical equipments with porcelain bushings is discussed based on shaking table test and finite element calculation. It is indicated that the absorber can not be applied in every condition.

For ground motions with significant short-period contents (most of ground motions belong to this type), it is satisfied with the damping effect of the absorber. If only considering the strain response at the foot of the bushing which controls damage state of the equipment, response is reduced 30%.

For ground motions with significant long-period contents, it is not clear of the damping effect of the absorber. Therefore, special support should be provided if using this kind of absorber.

The absorber should not be used to control the equipment response under near field ground motions with velocity-pulse.

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