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EFFECT OF SPRING ON OPERATING CHARACTERISTIC  
OF SPRING LOADED SAFETY VALVES

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ABSTRACT

It is well known about the principle of popping at spring loaded safety valves. It is also essential that the valves should operate surely judging by their purposes. In this study, operating tests have been carried out systematically using a safety valve, which belongs to lift type for air service and has a nominal size of 1 inch. In the beginning, we focussed on coiled spring which is one of the most important factors for balance of forces at safety valves. The influence of spring constant of coiled spring on operating characteristic of the valves is reported in this paper. And, the influence of spent coiled spring on it is also reported in detail.

1. INTRODUCTION

In air compressors, pressure vessels and the other industrial purposes, safety valves have been provided as the final safety device, which protects both pressure vessels themselves and their accessories from the destruction or the damage due to a rise in pressure. Therefore, a safety valve must open to release excess fluid accumulated in the vessel, as soon as the vessel pressure rises up to set one. This is the most important role of the valve from a safe standpoint. When the vessel pressure returns to set one again, the valve must close at once, if possible. This is also the important role of the valve from a economic standpoint.

Most of safety valves, which are in use at present, would be classified into direct spring loaded type.<sup>1)</sup> There are a few different things that mark the valve. The operation without power supply is one of them. A simple structure is the other one. Operating characteristics of the valve depend on the balance between both forces which face each other across valve disc, namely, inertia force of fluid flowing through the valve and compressive force of coiled spring. Safety valves are always desired to operate surely because of two standpoints described above.

But, it might be well that the former studies on safety valves are no more than a few ones. So, we decided to treat with spring loaded safety valve for gas service as an object of study. And, the goals of this study are to examine experimentally some factors which influence on the performance of the safety valve and to provide an information on the operating characteristics for designers and users. In this experiments, operating tests have been carried out systematically using a safety valve on the market, which belongs to lift type for air service and has a nominal size of 1 inch. In this paper, we focussed on coiled spring which is one of the most important factors for the valve. We will mainly report the experimental results concerning effect of coiled spring on operating characteristics.

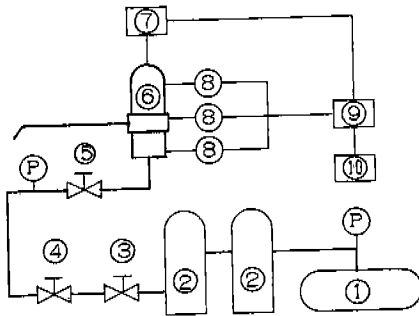
2. NOMENCLATURE

$d_s$  : diameter of piano wire  
 $F$  : computed values in forces exerted on valve disc due to coiled spring  
 $k$  : spring constant  
 $L$  : valve lift  
 $p_1$  : inlet pressure of safety valve  
 $p_2$  : outlet pressure of safety valve  
 $p_c$  : cap pressure of safety valve  
 $p_d$  : pressure at accumulator drum

- $p_r$  : set pressure at reducing valve  
 $p_s$  : set pressure at safety valve  
 $t$  : time after start of valve opening  
 $\Delta t$  : time for release of excess air

### 3. EXPERIMENTAL SETUP AND EXPERIMENTAL PROCEDURE

The experimental setup is diagrammed in Figure 1. Air compressor has an accumulator drum with a capacity of 83 liters. Besides the drum, a pair of the accumulator drums with a capacity of 230 liters are provided at the place between compressor and pipe line. After an accumulated air in the drums is depressed at pressure reducing valve, it flows to safety valve via solenoid controlled valve. Finally, it is to deliver to atmosphere. Pipe line downstream of the drums is made up of an inchd pipes and an inchd socket joints. Inlet pressure  $p_1$ , outlet pressure  $p_2$  and cap pressure  $p_c$  can be measured by each pressure taps as shown in Figure 2. The pressure taps are connected to



- ① AIR COMPRESSOR
- ② ACCUMULATOR DRUM
- ③ FLOW REGULATING VALVE
- ④ PRESSURE REDUCING VALVE
- ⑤ SOLENOID CONTROLLED VALVE
- ⑥ SAFETY VALVE
- ⑦ LASER DISPLACEMENT METER
- ⑧ PRESSURE TRANSMITTER
- ⑨ DIGITAL MEMORY
- ⑩ PEN RECORDER
- ⒫ PRESSURE GAUGE

Figure 1. Schematic of Experimental Setup

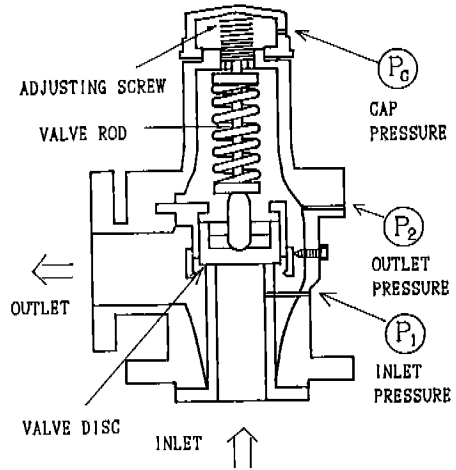


Figure 2. Schematic of Safety Valve

pressure transmitters through stainless steel pipes with a diameter of 1 mm. The transmitted signals lead to digital memory. Finally, they are outputted at pen recorder. On the other hand, the displacement of valve rod, which equals to that of valve disc, is detected by laser displacement meter. It is also outputted at pen recorder by way of digital memory. In the measurements on displacement, valve cap has always been taken off. And, regular valve rod was exchanged for the valve rod which is about two centimeters longer than regular one. The valve rod was specially made for this tests so that laser beam of displacement meter was able to reach on the top of the rod. Drum pressure  $p_d$  was always adjusted so as to equal the value by 0.294 MPa (3.0  $kg_f/cm^2$ ) higher than set one at safety valve whenever operating tests were carried out. By means of turn of adjusting screw, safety valve was set so that discharge just started at set pressure,  $p_s$ . The procedures of each measurements are as follows: As soon as solenoid controlled valve is opened, an air in the pipe line downstream of reducing valve must be pressured up to set pressure of reducing valve. Safety valve consequently leads to operate. Pressures and displacements

Table 1. Specifications of Coiled Spring

Name	Diameter of Material, $d_s$ mm	Spring Constant, $k$		Note	
		kN/m	kg <sub>f</sub> /m		
Spring A	3.5	7.9	0.81	Manufactured for Test	
Spring B	4.0	14.2	1.45		
Spring C	4.5	27.4	2.80		
Spring C'	4.5	32.3	3.30	New	ready-made
				Spent	

were measured while safety valve opened. The safety valve used in this experiments originally had a coiled spring which consists of a piano wire with a diameter  $d_s = 4.5$  mm. The specifications of the coiled spring are as followed : number of wrapping is 7, length without load is 60 mm and outer diameter of coiled spring is 33 mm. We made several kinds of coiled springs of same size and form as ready-made one. The details are shown in Table 1. To distinguish themselves, we adopted their name as a temporary expedient. Each values of spring constants shown in the table were really measured using a weight.

4. EXPERIMENTAL RESULTS

PRELIMINARY TESTS

As valve cap usually had to be put off in the measurement of valve rod displacement, namely in that of valve lift, preliminary tests using a safety valve without cap were carried out prior to operating tests. As the results of tests, cap pressures were found to be small. A comparison between the results without cap and those with cap was made concerning both inlet and outlet pressures of the valve and valve lift. A serious difference between them was not found. The facts would be fully explained by the reason that the safety valve used in this tests belongs to closed type, separating a cap from valve casing.

We then decided to carry out only

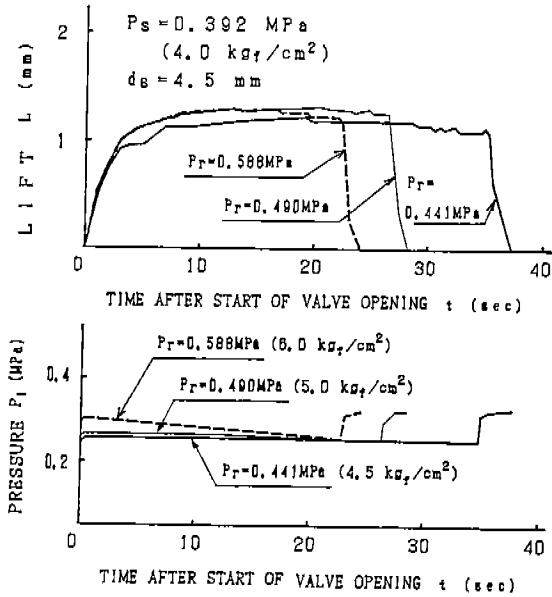


Figure 3. Comparison between Set Pressures at Reducing Valve

operating tests without cap. Both inlet and outlet pressures and valve lift were measured simultaneously in this operating tests.

RELATION BETWEEN SET PRESSURES OF REDUCING VALVE AND SET ONES OF SAFETY VALVE

In the case of holding set pressure at safety valve to be constant, both inlet and outlet pressures, and valve lift were measured using coiled spring C at several set pressures at reducing valve. Some of those results are shown in Figure 3. Both start to discharge pressure and reseating pressure at valve inlet, maximum value in outlet pressure and time for release of excess air are shown in Table 2.

Table 2. Comparison between Set Pressure at Reducing Valve

Set Pressure		Inlet Pressure		Maximum value		Time for Release of Excess Air
at Safety Valve	at Reducing Valve	Start to Discharge Pressure	Reseating Pressure	of Outlet Pressure	of Valve Lift	
$P_s$	$P_r$	$P_i$		$P_{e,max}$	$L_{max}$	$\Delta t$
MPa / ( kg <sub>r</sub> /cm <sup>2</sup> )		MPa /	kg <sub>r</sub> /cm <sup>2</sup>	MPa	mm	sec
0.196 (2.0)	0.245 (2.5)	0.127/1.3	0.123/1.3	0.002	1.49	74.0
	0.294 (3.0)	0.137/1.4	0.125/1.3	0.013	1.56	47.1
	0.392 (4.0)	0.159/1.6	0.122/1.2	0.029	1.67	44.7
0.392 (4.0)	0.441 (4.5)	0.265/2.7	0.256/2.6	0.020	1.56	32.0
	0.490 (5.0)	0.282/2.9	0.255/2.6	0.031	1.61	29.0
	0.588 (6.0)	0.312/3.2	0.263/2.7	0.045	1.65	23.5

For a set pressure at safety valve, the higher set pressure at reducing valve is established, the higher both start to discharge pressure and outlet pressure of safety valve rise. At the same time, it is also found that time for release of excess air becomes shorter obviously. The facts mentioned just above may be explained by following two claims :

1) The higher set pressures at reducing valve is established, the higher an air at the inlet and its vicinity of safety valve is pressurized. Then, volumetric ratio of air in the rear of the valve to one in front of that, so called expansion ratio, becomes growth with set pressure at reducing valve. It leads to increase in relieving capacity rate of safety valve.

2) In this study, the pressure at accumulator drums is to be set in compliance with set pressure at safety valve. In Table 2, it is also found that the reseating pressure at safety valve inlet mainly depends on set pressure at safety valve regardless of set pressure at reducing valve. After all, we may draw a following conclusion : time for release of excess air, whose quantity depends on set pressure at safety valve, becomes shorter with rising in set one at reducing valve.

COMPARISON BETWEEN DIFFERENCES IN DIAMETERS OF PIANO WIRE

In the case of varying only diameter of piano wire, which is a material of coiled spring, and of holding both size of valve casing and that of outer diameter of coil to be constant, the relations among pressures at inlet and outlet of safety valve, and valve lift have been examined in several kinds of set pressures at safety valve.

An example of experimental results on coiled spring is shown in Figure 4, which represents inlet pressure at safety valve and valve lift in the case

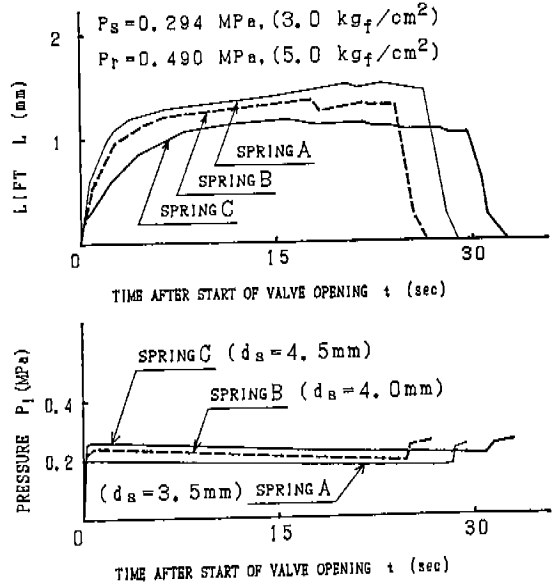


Figure 4. Comparison between Diameters of Piano Wire

of holding both set pressure at safety valve and that at reducing valve to be constant. The figure shows that the remarkable differences in valve lifts are largely due to diameters of piano wires. And, it also shows that the differences in inlet pressures are partially due to diameters. Those results may be summarized as follows: Table 1 shows that spring constant grows larger with diameter of piano wire. If contraction of coiled spring due to compression is kept a certain quantity, the compressive force of coiled spring grows larger with diameter of piano wire. If compressive force is kept a certain quantity, contraction of coiled spring is on the decrease with increase of diameter of piano wire. Because

forces exerted on valve disc due to compression of coiled spring grow stronger with increase of diameter of piano wire, inlet pressure at start to discharge is on increase and valve lift is reversibly on decrease with increase of diameter. Figure 4 shows the relation between valve lift and time after start of valve opening. It also shows that each of valve lifts of spring A and B rise up or blow down more steeply than that of spring C, and time for release of excess air with spring B is the shortest of three. From those results, it can be supposed that coiled spring B is most suited for such the condition as shown in the figure.

COMPARISON BETWEEN SPENT SPRING AND THE NEW ONE

To make a comparison between spent spring and the new one, operating tests were also carried out using both coiled springs. An example of the experimental results using coiled spring C and C' is shown in Figure 5. From the figure, following facts may be derived: Maximum value in valve lift of spent spring C' is smaller than that of new spring C. In the lift-time diagramm, valve lift with

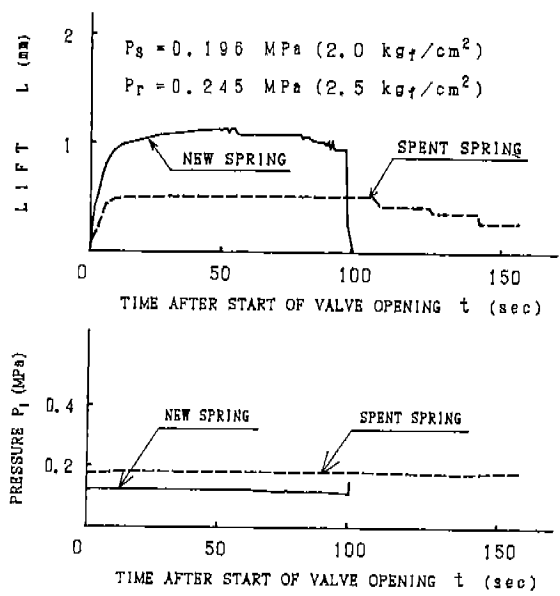


Figure 5. Comparison between Spent Spring and the new one

spent spring goes down gradually. The work hardening in coiled spring is caused gradually during valve operation. It leads to the increase of spring constant as shown in Table 1. It varies from 27.4 to 32.3 kN/m. Compression force on valve disc can be gained by smaller contraction of the spent one because of large spring constant. Then, it leads that valve lift of the spent one is smaller than that of the new one. If a safety valve has been operated frequently, or has been furnished for a long time, it requires that the coiled spring is examined at regular intervals. An example of computed values in compression force of coiled spring in the case of spring C and C' is shown in Table 3. Forces exerted on valve disc are computed as the product between spring constant and displacement of valve disc. The forces F shown in the table are constructed of both forces, namely, the compression force due to tightening of adjusting screw at valve setting and that due to valve lift. With respect to the computed values shown in the table, it is found that the difference between spent spring and the new one at lower set pressure of reducing valve is greater than that at

Table 3. Computed Values in Forces due to Coiled Spring

Set Safety Valve	Pressure Reducing Valve	Computed Values in Forces exerted on Valve Disc due to Coiled Spring			Kind of Spring : $d_s = 4.5 \text{ mm}$
	$P_s$	$P_r$	Total Forces F : N / ( kgf )		
MPa / ( kgf/cm <sup>2</sup> )		Tightning	Lift	Total	New or Spent
0.196 ( 2.0 )	0.245 ( 2.5 )	97.0  ( 9.9 )	32.4 (3.3)	129.4 (13.2)	New Spring
	0.294 ( 3.0 )		15.7 (1.6)	112.7 (11.5)	Spent Spring
			29.4 (3.0)	126.4 (12.9)	New Spring
	0.392 ( 4.0 )		21.6 (2.2)	118.6 (12.1)	Spent Spring
			36.3 (3.7)	133.2 (13.6)	New Spring
	33.3 (3.4)		130.3 (13.3)	Spent Spring	
0.490 ( 5.0 )	0.539 ( 5.5 )	259.7 ( 26.5 )	32.3 (3.3)	292.0 (29.8)	New Spring
		31.4 (3.2)	291.1 (29.7)	Spent Spring	

higher set pressure of one. This is due to the fact that the difference between the components on valve lift at lower set pressure of reducing valve becomes larger. This may be explained by two kinds of reasons as follows : When set pressure at safety valve is established higher, the ratio of forces due to tightening of adjusting screw to total forces becomes larger but the force due to tightening has no difference between spent spring and the new one. Therefore, we should pay attention to spent coiled spring of safety valve in the case of both lower pipe line pressure and larger valve lift.

### 5. CONCLUSION

In this study, operating tests have been carried out using a spring loaded safety valve for air service. Following conclusions on operating characteristics were obtained in the measurements on both inlet and outlet pressures of safety valve and valve lift.

1) Relation between pipe line pressures upstream of safety valve and set pressures at safety valve :

Pipe line pressures upstream of safety valve deeply influence on start to discharge pressure at safety valve inlet, outlet pressure of safety valve, valve lift and relieving capacity rate.

2) Diameter of wire materials and spring constant :

In coiled springs used in this experiments, spring constants naturally increase with diameter of wire

materials. Larger spring constants lead to higher pressure at safety valve inlet and to smaller valve lift.

There are the optimum size in diameter of wire material for operating characteristic according to set pressure at safety valve.

3) Spent coiled spring :

If safety valve repeats its operation frequently, the spring constant of coiled spring leads to increase because of work hardening. Both valve lift and relieving capacity rate in safety valve with spent coiled spring tend to become smaller than those in that with the new one. It seems that the restriction on coiled spring in use have not been established before.<sup>2)</sup> So, we will propose that safety valve should be limited in frequency of operation.

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