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THE VIBRATION OF CONTACTS OF AN ELECTROMAGNETIC RELAY

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Abstract: The article deals the vibration of contacts of electro-mechanical relays (and mechanical contacts generally), its properties, its measurement and a special measuring instrument built for this purpose.

The vibration of contacts is caused by ringing of the springs (and other mechanical components) carrying the contacts. It generates quasiperiodic interruptions of current flowing through a moving contact-pair. These interruptions cause problems e.g. when this current controls fast semiconductor circuits or when the contact-pair is loaded by a remarkable current and sparks and burning of contacts comes in. To avoid these problems some linear or nonlinear filters must be introduced. The measurement of this phenomena has shown that the vibrations mentioned here affect remarkably the time parameters (different delays) describing the behavior of the relay and that these parameters become to be random. The statistical characteristics of these parameters contain information about the technical (diagnostic) state of the relay, which is important for estimation of the behavior of the relay in future. Finally, the basic data of the measuring instrument are introduced.

Keywords: Electro-mechanical relay, vibration of contacts, burning of contacts, diagnostic state

1 INTRODUCTION

The electromechanical relay is called neutral when its function does not depend on the direction of the electric current flowing through its coil. This simplest arrangement of a relay is shown in Fig. 1. It consists of a frame 7 stiffly connected with the coil 9 and with contact springs 1, 2 and 3.These contact springs are mounted stiffly on one of their ends (left), while on their other free (right) ends are arranged the contacts lentils. The contact springs 2 (so called operating or switch-on contact) and 3 (so called release or switch-off contact) have their basic (but a little elastic) positions. The contact spring 1 (the moving or the middle contact) is fixed on its left end, but its free (right) end is moved by the anchor 6, being driven by an electromagnet 9.

Each of contact springs (1, 2 and 3) may be considered as a girder being fixed on its one (left) end and loaded on its free (right) end by the mass of the contacts lentils and by the forces risen due to the elastic deformation of these springs. These girders create mechanical ringing circuits with relatively high quality. Their oscillations are excited when the moving contact 1 impacts the operate contact 2 (or the release contact 3) and also when the moving contact 1 leaves the release contact 3 (or the operate contact 2).

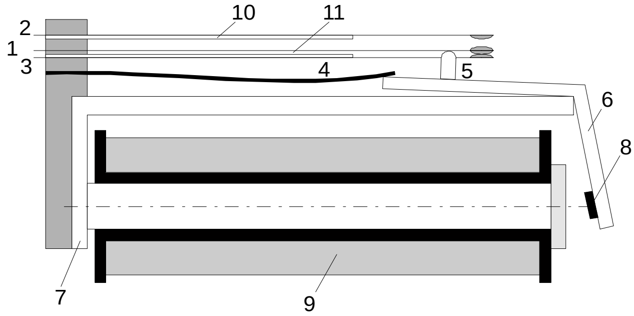

Figure 1. Basic arangement of a neutral relay

2 THE BEHAVIOR OF THE RELAY

The immediate state of each contact will be described by its conductivity. We shall consider only two values of conductivity of a closed and an opened contact pair: The greatest and the smallest one. The shape of separate changes of conductivity is considered as rectangular. This consideration is fully suficient when the mechanical behavior of contacts should be described because the frequency components of the mechanical motion of contacts lie below 10 kHz. On other hand, if we try to describe the effects arising due to the bilateral sliding of surfaces of contact lentils during the switching action, the mentioned consideration becomes to be unacceptable because the frequency components of the changes of conductivity reach frequencies up to 10 MHz.

An example of the behavior of an operate (switch-on) contact and a release (switch-off) contact is shown in Fig. 2, where the graph U_N represents the voltage on the coil of the relay, the graph G_S shows the conductivity of the operate contact and the graph G_R shows the conductivity of the release contact.

On the graph G_S we can see four basic parameters of the closing of the operate contact:

1) T_{S1} is the delay between the start of energizing of the coil of the relay and the moment of the first touch between the moving contact (1) and the operate contact (2).
2) T_{K1} is the interval between the start of energizing of the coil and the moment, when permanent connection between the moving contact and the operate contact was reached.
3) T_{Z1} represents the difference between both parameters mentioned above. It is the interval - the bounce time - when the ringing of the contact springs causes the interruptions of the closing of the operate contact.
4) N_1 is the number of interruptions which have appeared during the bounce time, described in the previous point.

Analogic parameters we can see in the right part of the graph G_S:

1) T_{S2} is the delay between the moment when the coil was deenergized and the moment when the connection on the operate contact was interrupted first times.
2) T_{K2} is the delay between the moment when the coil was deenergized and the moment when the operate contact became opened forever.
3) T_{Z2} represents the difference between both intervals mentioned above. During this interval - the bounce time - the ringing of the contact springs causes semiperiodic closing and opening of the operate contact.
4) N_2 is the number of interruptions during the bounce time interval T_{Z2}.

In the graph G_R is shown analogic behavior of the release contact. The left part of this graph shows the opening of the release contact when the coil has been energized. Hence, the interval T_{S3} is analogous to T_{S2} (see graph G_S). In the same way T_{Z3} is analogous to T_{Z2} , T_{K3} to T_{K2}, N_3 to N_2 and likely T_{S4} to T_{S1}, T_{Z4} to T_{Z1}, T_{K4} to T_{K1} and N_4 to N_1.

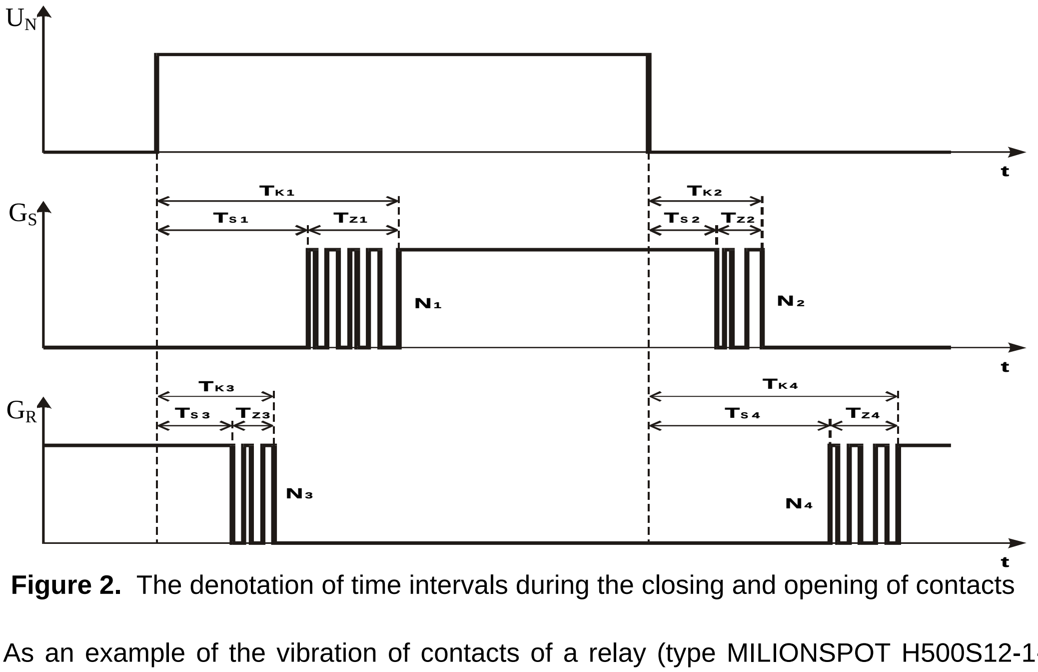

Figure 2. The denotation of time intervals during the closing and opening of contacts

As an example of the vibration of contacts of a relay (type MILIONSPOT H500S12-1-C) we introduce the results of one real measurement of the courses U_N, G_S and G_R. These results are arranged in Table 1 with using the denotation of groups of impulses explained in Fig. 2. The rectangular shape of impulses allows us to desribe each individual impulse by two numbers only: t_i represents the moment of the start (leading edge) of the impulse and t_{wi} represents its width. . This simplifies the creation of statistics and calculation of statistical parameters.

Table 1. The intervals measured at the relay MILIONSPOT H500S12-1-C

Operation of the relay	Closing of operation contact	T_{S1} = 6,18 ms, T_{K1} = 6,72 ms, N = 6						
		Imp. I	1.	2.	3.	4.	5.	6.
		t_i [ms]	6,18	6,24	6,28	6,49	6,53	6,68
		t_{Wi} [ms]	0,02	0,04	0,04	0,04	0,10	0,04
	Open. of oper. con.	N = 0, T_{S2} = T_{K2} = 3,91 ms						
Release of the relay	Oper. of rel. cont.	N = 0, T_{S3} = T_{K3} = 7,26 ms						
	Closing of release contact	T_{S4} = 8,03 ms, T_{K4} = 14,55 ms, N = 5						
		Imp.	1.	2.	3.	4.	5.	-
		t_i[ms]	8,03	8,18	10,88	11,01	13,02	-
		t_{Wi} [ms]	0,04	0,71	0,07	0,76	1,19	-

In this example the closing of the operate contact pair and the closing of the release contact pair only causes the vibrations, while the opening of both of these contact pairs passes without any vibration. It is very difficult to avoid the vibration excited by the impact of contact lentils by using of mechanical means and for this reason the vibration appears practically everytimes when a contact pair is closing. But when a contact pair is opening the vibration need not appear or, at least, the number of individual impulses being generated is usually smaller than at closing.

In the following four tables (Tab. 2 - Tab. 5, next page) there are summarized the results of five experiments, analogous to the experiment shown in *Tab. 1*, but slightly simplified (the intervals T_{S1} … T_{R4} and the numbers N_1 … N_4 of single impulses are introduced, while the moments t_i and and widths t_{wi} are omitted). The denomination of time intervals corresponds to Fig. 2. These experiments were realized with four relays of different types. For each parameter is shown its average value. Generally we may see, that relays of higher quality present lower number if impulses excited by the switching actions.

3 RANDOMNESS OF PARAMETERS

The tables Tab. 2 - 5 show the fact that practically all parameters of a relay are random quantities. Each closing or opening of a contact pair represents a unique action which produces its own results (like in Fig. 2 or in Tab. 1). Hence, the parameters reached by individual measurements must be arranged into statistical sets which must be evaluated, and only then we obtain generally valable parameters. In the tables Tab. 2 - 5 there are shown the results of the simplest evaluation of very small statistical sets (each involving five elements only) - the average values.

In practice the evaluation of statistical sets must be based on remarkably higher number of single measurements, because the ergodicity of these random processes is not warranted. The ergodicity may be considered over short time intervals only (in comparison with the lifetime of the relay). During long time intervals the parameters of each relay evolve. Moreover, the parameters of each relay depend on different factors, inclusive the number of realized switching actions, supply voltage, load of contacts, temperature, etc. Also these dependences evolve over long time intervals. The influence of each of these factors may be ascertained and the acquired knowledge may allow us tu predict the behavior of the relay in future and eventually estimate its remaining lifetime. For this purpose there were created various modes of recording of these dependences, mostly being expressed statistically.

One of them is the dependence of the operate delay T_{K1} (in milliseconds, see T_{K1} in Fig. 2) on the exciting voltage $U_{N,}$ or on the exciting power of the coil, see Fig. 3. This dependence can not be drawn as a line, but it must be drawn as a band. It expresses that a dispersion of the values of T_{K1} is present. The same we can see in Fig. 3 for the release delay T_{K2} (see Fig.2); its band is drawn by a dotted line. Both dependences were taken from [1] and result from the evaluation of measurements of ten pieces of the relay TAKAMISAWA A-5W-K.

The expression of two dependences by the aid of their distributions is shown in Fig. 4. The distributions of operate and release voltages are shown here. The exciting voltage (U_N) of the coil of the relay is given indirectly, as a per cent fraction of its nominal voltage [1]. The expression of dependences by the aid of distributions is suitable when a higher number of elements is taken in account (in the examples in Fig. 4, 5 and 6 there are 240 pieces of relays TAKAMISAWA A-5W-K).

Table 2. Numbers of impulses and time intervals measured at the relay MILIONSPOT H500S12-1-C

Measure-ment No	Operation of the relay						Release of the relay					
	Operation contact			Release contact			Operation contact			Release contact		
	T_{S1} [ms]	T_{R1} [ms]	N_1 [-]	T_{S3} [ms]	T_{R3} [ms]	N_3 [-]	T_{S2} [ms]	T_{R2} [ms]	N_2 [-]	T_{S4} [ms]	T_{R4} [ms]	N_4 [-]
1	6,14	6,44	2	3,80	3,80	0	7,47	7,47	0	8,24	14,57	6
2	6,20	6,54	3	3,95	3,95	0	7,35	7,35	0	8,12	14,51	6
3	6,24	6,58	3	3,47	3,75	1	7,30	7,30	0	8,06	14,48	6
4	6,26	6,71	5	3,57	3,73	1	7,25	7,25	0	8,01	14,45	7
5	6,29	6,78	4	3,56	3,74	1	7,22	7,22	0	7,97	14,42	7
Average	6,23	6,61	3,4	3,67	3,79	0,6	7,32	7,32	0,0	8,08	14,49	6,4

Table 3. Numbers of impulses and time intervals measured at a usual telecommunication relay

Measure-ment No	Operation of the relay						Release of the relay					
	Operation contact			Release contact			Operation contact			Release contact		
	T_{S1} [ms]	T_{R1} [ms]	N_1 [-]	T_{S3} [ms]	T_{R3} [ms]	N_3 [-]	T_{S2} [ms]	T_{R2} [ms]	N_2 [-]	T_{S4} [ms]	T_{R4} [ms]	N_4 [-]
1	37,53	38,32	6	37,04	37,04	0	28,26	28,26	0	29,07	29,84	7
2	36,98	38,07	5	36,31	36,31	0	28,14	28,33	1	29,10	29,29	1
3	36,91	37,57	5	36,31	36,31	0	28,24	28,24	0	29,16	29,73	3
4	36,67	37,29	4	35,87	35,84	0	28,09	28,09	0	29,16	29,97	4
5	36,50	37,61	5	35,66	36,38	3	28,58	28,58	0	29,01	30,01	5
Average	36,92	37,77	5,0	36,24	36,38	0,6	28,26	28,30	0,2	29,10	29,77	4,0

Table 4. Numbers of impulses and time intervals measured at a relay [RP120] formerly used for the purposes of automation in industry

Measure-ment No	Operation of the relay						Release of the relay					
	Operation contact			Release contact			Operation contact			Release contact		
	T_{S1} [ms]	T_{R1} [ms]	N_1 [-]	T_{S3} [ms]	T_{R3} [ms]	N_3 [-]	T_{S2} [ms]	T_{R2} [ms]	N_2 [-]	T_{S4} [ms]	T_{R4} [ms]	N_4 [-]
1	30,97	32,38	6	19,71	19,71	0	31,60	31,60	0	38,73	40,93	7
2	32,34	33,78	5	22,25	22,25	0	31,27	31,27	0	38,32	40,32	6
3	32,49	33,91	5	22,81	22,81	0	31,88	31,88	0	38,19	40,47	7
4	32,54	33,95	5	22,37	22,37	0	30,91	31,10	1	38,13	40,12	7
5	32,53	33,93	5	22,46	22,46	0	30,08	30,97	4	38,08	41,16	8
Average	32,17	33,59	5,2	21,92	21,92	0,0	31,15	31,36	1,0	38,29	40,60	7,0

Table 5. Numbers of impulses and time intervals measured at a relay formerly appointed for military purposes [LUN 2621.4/503]

Measure-ment No	Operation of the relay						Release of the relay					
	Operation contact			Release contact			Operation contact			Release contact		
	T_{S1} [ms]	T_{R1} [ms]	N_1 [-]	T_{S3} [ms]	T_{R3} [ms]	N_3 [-]	T_{S2} [ms]	T_{R2} [ms]	N_2 [-]	T_{S4} [ms]	T_{R4} [ms]	N_4 [-]
1	5,21	5,28	1	3,70	3,87	1	8,42	8,42	0	9,88	9,97	1
2	5,24	5,32	1	3,73	3,91	1	8,42	8,42	0	9,87	9,96	1
3	5,24	5,24	0	3,84	3,90	1	8,42	8,42	0	9,87	10,04	3
4	5,24	5,33	1	3,85	3,90	1	8,42	8,42	0	9,89	10,03	2
5	5,25	5,39	2	3,85	3,90	1	8,44	8,44	0	9,89	10,03	2
Average	5,24	5,31	1,0	3,79	3,90	1,0	8,42	8,42	0,0	9,88	10,01	1,8

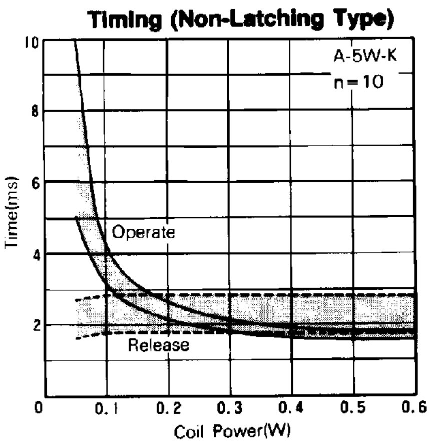

Figure 3. The operate delay T_{K1} and the release delay T_{K2} of a relay

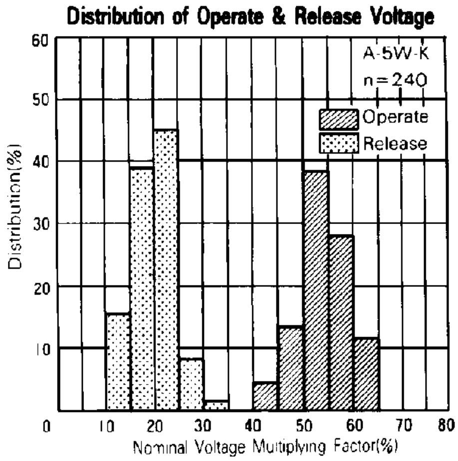

Figure 4. The distributions of the operate and release voltages of a relay

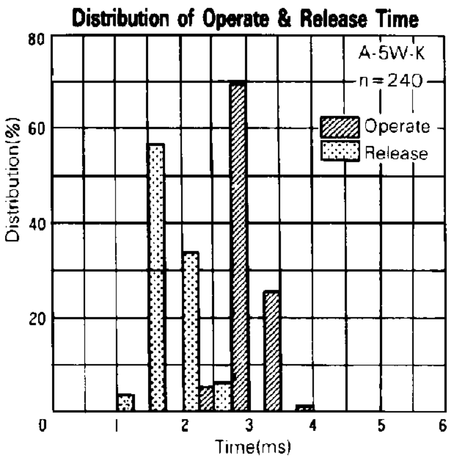

Figure 5. The distributions of the operation delay T_{K1} and release delay T_{K2} at a relay

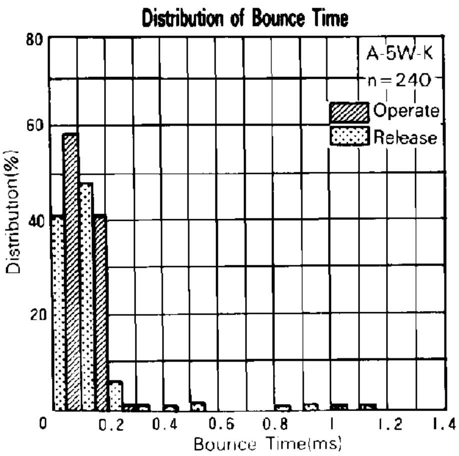

Figure 6. The distribution of the bounce times T_{Z1} and T_{Z2} at a relay

4 THE MEASURING INSTRUMENT

Due to the necessity of performing of very large number of measurements, a special measuring instrument has been built. It is based on the Micro Computer Unit Motorola MC68HC11 and its block scheme is shown in Fig. The control circuit consists of the MCU (with keyboard and display), which is connected to a PC by a RS 232 bus. Three operating blocks are connected to the MCU via its I/O ports: The block of power supply for the coil of the relay being measured (relay under test), the block of measuring of its contacts and the block of loading of these contacts. When the relay has more groups of contacts, then contacts of each group must be measured separately. The whole instrument is controlled from the PC via the RS232 bus. It does mean that the program may bee prepared in the PC and loaded into the memory of MCU which controls the individual operations in detail, without subsequent communication on the RS 232 bus.

There is possible to measure the relay as fast as it is able to reach the mechanical stabile state after each switching action. Practically there is possible to switch (open and close the operate or release contacts) ten times per second. Hence, the duration of a meaurement with one million of switching actions requires approximately 28 hours.

The apparatus offers following basic possibilities of measurement of a relay: A- Measuring of static characteristic of the relay, B- measuring of vibration of contacts, C- measuring of transition resistance of the closed contacts, D- measuring of transient response and E- measuring in cyclíc regime.

To allow all named measurements at different types of relays there is possible to set following quantities: 1- The nominal voltage(of the coil of the relay), 2- the slope of nominal voltage (when the static characteristic is being measured), 3- the type of contacts, 4- the current flowing through a closed

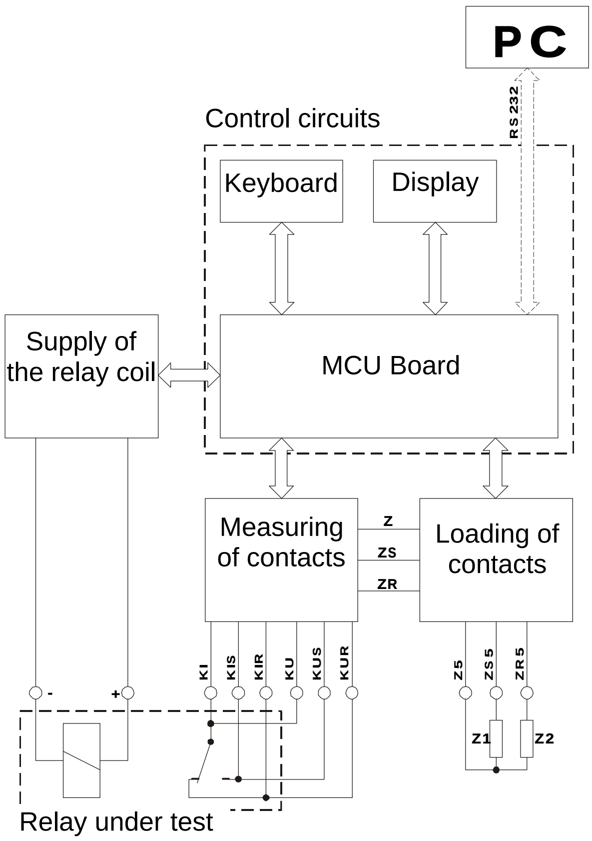

Figure 7. The block scheme of the measuring *apparatus.*

contact pair (when the transition resistance is being measured), 5- the width of exciting impulses and 6- the number of these impulses (when the transient response is being measured), 7- the frequency, 8- the duty cycle, 9- the number of cycles and 10- the type of load contacts (when the cyclic measurement is performed).

For the practical use of the instrument there are important also these auxiliary functions: a- The calibration of the voltage source, b- the calibration of the current source and c- the calibration of the digital voltmeter.

The contacts may be loaded either by an external load or by one of four prepared impedances. The voltage used for these measurings is either 24 or 48 V DC. The transition resistance of contacts is calculated from the voltage drop over the closed contact pair being loaded by a constant DC current. This current may be set in steps 0,1 … 1 A.

5 AN EXAMPLE OF RESULTS

The measurings named above may be used for various purposes. In Tab. 7 there are introduced results of measurings concerned on the so called "wearing out" or "growing old" of a relay. The first expression is better, because the technical state of a relay is determined by the number N of performed switching actions rather than by the time of existence of the relay. Three examples are shown: 1- The (minimal) operate voltage U_S (analogous behavior shows the maximal release voltage U_R), 2- the transition resistance R_S of the closed operate contact pair (analogic is the transition resistance R_R of the closed release contact) and 3- the shortest impulse t_w of the exciting voltage U_N being sufficient to start and perform a complete switching action.

Table 7. The dependences of selected parameters of a relay on the number N of switching actions

N [-]	300000	400000	500000	600000	700000	800000	900000	1000000
U_S [V]	7,2	7,3	7,3	7,5	6,5	6,4	6,7	6,4
R_S [Ω]	11	13	15	15	19	22	15	18
D_{SS} [Ω]			3,0	1,76	0,02	1,18	1,01	0,68
t_W [ms]	6,0	6,0	6,5	6,5	5,75	5,25	5,5	5,75
D_{Stw} [ms]			0,108	0,081	0,066	0,077	0,026	0,005

The parameters shown in *Tab. 7* have following properties: The voltage U_S (and U_R) decreases directly with rising number N of cycles. The resistance R_S (and R_R) does not show any outstanding property, but its sliding (successive) dispersion D_{SS} (and D_{SR}) decreases too. The same is valid for the length of impulse t_w itself and for its sliding dispersion D_{Stw}..All these symptoma show that after (approximately) 800000 cycles the relay under test reaches its best mechanical condition. The wearing out of the relay has not appeared and it may come approximately after ten millions of cycles.

REFERENCES

[1] Fujitsu Takamisawa: Miniature relay A - series, Component Catalogue
[2] Siemens: Miniature relay P2 - A product information

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