The Effects of Gamma Radiation on Electric Characteristics of the Electronic Circuit Components. (I)

Takashi NAKAKADO* and Toshifumi SAIGUSA**

(Takarazuka Radiation Laboratory, Sumitomo Atomic Energy Industries, Ltd., Takarazuka)

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Five kinds of the electronic circuit components were irradiated by Co^{60} gamma rays with doses of $10^6 \sim 10^7$ r. The effects of the radiation on these elements, resistors, condensers, solid diodes, tranistors and magnetic cores, were measured during and after the irradiation. Some changes of properties of the elements were explained to be partially due to the production of positive or negative vacancies produced in materials used by the radiation, however, many phenomena observed seemed to be very complicated and not endure the simple interpretation. In spite of the scatter of measured data and difficulty of the interpretation for observed phenomena, by this preliminary survey on the effects of gamma rays on the electronic circuit components it is revealed that some constants are influenced so much that the characteristics of the electronic circuit composed of these elements would change considerably when the system is used in an intense radiation field. The more systematic investigation should be necessary to get valuable knowledge which would be helpful for the workers who are employing the electronic apparatuses in the intense gamma ray field.

INTRODUCTION

As the peaceful uses of atomic energy progressed, the application of the electronic instruments constructed from various kinds of parts in the intense radiation field has rapidly increased. The purpose of the present preliminary work is to find the effects of gamma radiation on these electronic components as well as to obtain any valuable knowledge which is of practical importance and may be helpful for the future design and improvement of the electronic instruments to be used in the high radiation field. As the first step of research along this line some electronic parts, most commonly used and easily commercially available ones, were examined on the change of their electric characteristics under the irradiation of gamma rays from Co^{60} with doses of the order of $10^6 \sim 10^7$ r.

EXPERIMENTAL METHOD

The sample used in the present work are ones commonly used in our electronic circuits and easily available in our market. Number of the examined pieces and their manufacturers are listed in Table 1.

All samples used were irradiated by the gamma rays from Co^{60} in the center

* 中門 孝

** 三枝利文 (Now at Shimizu Laboratory, Institute for Chemical Research, Kyoto University)

of the cylindrical source cage of our 2 kC irradiation facility[1]. The dose rate at the place where the test samples were irradiated was estimated to be 5.2×10^5 r/hr when the present series of experiments was performed. In the cases of the carbon resistors the samples were placed in this gamma-ray field at room temperature for about 20 hours and during the irradiation changes of resistance values of six pieces were recorded continuously in parallel, while in the cases of condensers, solid diodes and magnetic cores measurements were carried out four times during the course of the irradiation at room temperature; before irradiation, at 1.0×10^6 r, at 1.0×10^7 r, and about 30 minutes after an irradiation of 1.0×10^7 r. For the examined transistors, measurements under the irradiation were impossible because of some troubles inherent in the measurements of characteristics of the transistors. In some properties of the transistors irradiated the annealing effects were revealed by measurements after the irradiation. Only in the cases of chemical condensers (alminium electrode) and magnetic cores (μ_0-cores) some constants were measured eight and thirteen times, respectively,

Table 1. Irradiated electronic circuit components.

Sample		Manufacture	Nominal value	Number of test pieces
Resistor				
Carbon solid resistor		Matsushita Elec. Ind. Co.	1 MΩ	6
		Tama Elec. Co.	1 MΩ	6
Carbon film resistor		Matsushita Elec. Ind. Co.	1 MΩ	6
		Riken Dengu Co.	1 MΩ	6
Condenser				
Mica condenser	A	Fuji Tsushinki Ind. Co.	1000 pF	5
	B	N. T. K. Co.	1000 pF	5
	C	Miyama Elec. Co.	1000 pF	5
Ceramic condenser	A	Murata Mfg. Co.	1000 pF	5
	B	Taiyoh Yuden Co.	1000 pF	5
	C	Matsushita Elec. Ind. Co.	1000 pF	5
Styrol condenser	A	Matsushita Elec. Ind. Co. (I)	1000 pF	5
	B	Matsushita Elec. Ind. Co. (II)	1000 pF	5
	C	Fuji Tsushinki Ind. Co.	1000 pF	5
Mylar condenser	A	Matsushita Elec. Ind. Co.	1000 pF	5
	B	Fuji Tsushinki Ind. Co.	1000 pF	5
Chemical condenser (Tantal electrode)	A	Matsushita Elec. Ind. Co.	10 μF	5
	B	Nippon Chemical Condenser Co.	10 μF	5
Chemical condenser (Alminium electrode)		Tokyo Elec. Co.	10 μF	5
Solid diode				
1S32, 1S81		Tokyo Shibaura Elec. Co.		5
1T22, 1T23		Sony Elec. Co.		5
1N38A, HR-12		Hitachi, Ltd.		5
1N54A, SD104		Nippon Elec. Co.		5
0A81, MA209		Matsushta Elec. Ind. Co.		5

Transistor			
Power or L. F. transistor			
2SB80	A	Hitachi, Ltd.	5
2SB137	B	Mitsubishi Elec. Co.	5
2SB26	C	Tokyo Shibaura Elec. Co.	5
2SB107	D	Nippon Elec. Co.	5
2SB74	E	Hitachi, Ltd.	5
2SB171A	F	Matsushita Elec. Ind. Co.	5
2SB134	G	Mitsubishi Elec. Co.	5
2SB111	H	Nippon Elec. Co.	5
2SB48	I	Sony Elec. Co.	5
H. F. or I. F. transistor			
2SA31	A	Kobe Kogyo Corp.	5
2SA167	B	Nippon Elec. Co.	5
2SA145C	C	Matsushita Elec. Ind. Co.	5
2SA53	D	Tokyo Shibaura Elec. Co.	5
2SA12	E	Hitachi, Ltd.	5
2SA141	F	Mitsubishi Elec. Co.	5
H. F. or convertor transistor			
2SA15	A	Hitachi, Ltd.	5
2SA144D	B	Matsushita Elec. Ind. Co.	5
2SA30	C	Kobe Kogyo Corp.	5
2SA143	D	Mitsubishi Elec. Co.	5
2SC75	E	Sony Elec. Co.	5
2SA51	F	Tokyo Shibaura Elec. Co.	5
Magnetic core			
Memory or switching core			
BZ-120		Matsushia Elec. Ind. Co.	5
FR-30		Tohoku Metal Ind. Co.	5
μ_0-core			
LIT-19-2	A	Tokyo Elec. Chem. Co.	4
B2R	B	Taiyoh Yuden Co.	4
SW-1	C	Matsushita Elec. Ind. Co.	5
OBIT-19-2	D	Tokyo Elec. Chem. Co.	5

during the irradiation to obtain the indication to further steps of the work. More details of each measurement are described in the following section.

RESULTS

i) Resistors

Resistances were recorded outside the hot cave by applying 200 V d.c. voltage to the samples. After the irradiation of 10^7 r, resistances of carbon solid resistors decreased about 1~3%, on the other hand those of carbon film resistors decreased only 0.5%. Evidently, this arises from the difference of number of carriers produced by the irradiation of the gamma rays. All samples showed the same tendency by the irradiation.

ii) Condensers

Since the volume in the center of cylindrical source cage was so small, only 15 samples were measured at each run. Capacitance and tanδ were measured by applying 1000 c/s, 5 V a.c. voltage to the samples and by the use of a capacitance-bridge and oscilloscope. Insulation resistance was measured only in the cases of mica condensers and ceramic condensers by the use of a vibrating reed electrometer. For styrol condensers and mylar condensers, insulation resistance was not measured, because it was same or larger than that of the polyethylene covered co-axial cables used. In the case of chemical condensers, leak current was measured 5 minutes after application of related voltages. Results with condensers are as followings :

a) Mica condensers. The variation of properties from initial values by the irradiation are shown in Table 2 in percentage.

Table 2. Variations of constants of the mica condensers.

Measured constants	Before irrad.	Variations		
		10^6r irrad.	10^7 r irrad.	30 min. after irrad.
Capacitance				
Sample A	983 pF	−2.5%	+0.7%	+0.3%
Sample B	983	+0.7	+1.2	+1.3
Sample C	951	+0.9	+0.1	+1.5
tan δ				
Sample A	19.6×10^{-4}	−18.4%	+121.4%	+49.5%
Sample B	20.4	−24.5	+120.6	+14.2
Sample C	20.9	−25.4	+ 76.6	−25.2
Insulation resistance				
Sample A	$3.9\times10^{12}\Omega$	$2.4\times10^{10}\Omega$	$6.0\times10^{10}\Omega$	$3.3\times10^{12}\Omega$
Sample B	2.7×10^{12}	7.1×10^{10}	3.1×10^{10}	3.9×10^{12}
Sample C	7.6×10^{11}	4.3×10^{10}	6.8×10^{10}	8.4×10^{11}

Listed values are the averaged values for five examined sample.

Although characteristic tendencies were not found in the change of capacitance and tan δ, insulation resistance decreased about two orders after a 10^6 r irradiation, however, no further remarkable changes were observed even when the total irradiation dose was increased more. This tendency of insulation resistance was common to three types of mica condensers examined. Observing the annealing process at room temperature after irradiation it was found that the value of insulation resistance rapidly regain almost its initial value.

b) Ceramic condensers. Variation of capacitance by irradiation was larger than that induced in mica condensers, at most within 10%, while that of tanδ was generally smaller than that observed with mica condensers. Degradation in insulation resistance was observed to be almost same in the case of mica condensers, but annealing was relatively slower, as shown in Table 3.

Table 3. Variations of constants of the ceramic condensers.

Measured constants	Before irrad.	Variations		
		10^6 r irrad.	10^7 r irrad.	30 min. after irrad.
Capacitance				
Sample A	1053 pF	−1.8%	− 3.2%	− 2.6%
Sample B	1673	+8.5	+10.3	+ 8.4
Sample C	901	+1.4	+ 2.4	+ 2.2
tan δ				
Sample A	164.6×10^{-4}	−9.6%	−24.3%	− 8.9%
Sample B	186.4	−7.5	+29.3	+37.1
Sample C	43.2	−3.0	−36.8	− 3.0
Insulation resistance				
Sample A	$3.1\times10^{12}\Omega$	$0.7\times10^{11}\Omega$	$0.6\times10^{11}\Omega$	$0.6\times10^{12}\Omega$
Sample B	1.4×10^{12}	0.7×10^{11}	0.6×10^{11}	1.1×10^{12}
Sample C	1.0×10^{12}	0.8×10^{11}	0.9×10^{11}	0.7×10^{12}

Listed values are the averaged values for five examined samples.

c) Styrol condensers. Capacitance of two types out of three sammples increased up to within 2% as the total dose increased, while another increased to 4.4%. All of them rapidly became again initial values after the irradiation. Table 4 shows the percentages of variation under and after the irradiation. It is noted also that in this case changes of tanδ value were found to be between those observed in former two cases.

Table 4. Variations of constants of the styrol condensers.

Measured constants	Before irrad.	Variations		
		10^6 r irrad.	10^7 r irrad.	30 min. after irrad.
Capacitance				
Sample A	932 pF	+1.7%	+4.4%	−1.1%
Sample B	1034	+1.3	+1.5	+0.3
Sample C	976	+1.5	+1.7	+0.3
tan δ				
Sample A	41.6×10^{-4}	−63.9%	−87.5%	−8.2%
Sample B	32.8	−66.5	−85.1	−64.9
Sample C	16.3	+22.7	−33.7	+12.3

Listed values are the averaged values of five examined samples.

d) Mylar condensers. Much different changes of electrical characteristics were found between two kinds of samples of mylar condensers examined. Variation range of capacitance was +4.0∼−1.5% and that of tanδ wass +8.0∼

−43.0%. Although the mylar condenser consisting of a thin film of polyethylene-terephthalate showed similar electrical characteristics to the styrol condenser made of polystyrene, changes of its characteristics induced by the irradiation were remarkably different each other, and so no distinct characteristic tendency was observed. Percentages of variations in mylar condensers from initial values are shown in Table 5.

Table 5. Variations of ccnstants of the mylar condensers.

Measured constants	Before irrad.	Variations		
		10^6 r irrad.	10^7 r irrad.	30 min. after irrad.
Capacitance				
Sample A	1043 pF	+0.6%	−1.5%	−0.1%
Sample B	1008	+2.6	+2.7	+3.7
tan δ				
Sample A	52.6×10^{-4}	−13.3%	− 1.1%	−17.5%
Sample B	39.6	−42.4	− 21.2	+ 7.6

Listed values are the averaged values of five examined samples.

e) Chemical condensers (tantal electrode). As the total dose increased, capacitance decreased but tan δ increased. Leak current increased rapidly as soon as the irradiation started, thereafter changed not so much and showed a tendency to saturate. After the irradiation these three factors, capacitance, tan δ, leak current, rapidly regained the initial values ; see Table 6.

Table 6. Variations of constants of the chemical condensers (tantal electrode).

Measured constants	Before irrad.	Variations		
		10^6 r irrad.	10^7 r irrad.	30 min. after irrad.
Capacitance				
Sample A	11.0 μF	−0.4%	−1.6%	−4.0%
Sample B	11.0	+0.7	+0.1	−1.2
tan δ				
Sample A	162.6×10^{-4}	+50.2%	+114.0%	+140.3%
Sample B	143.1	+37.1	+ 67.2	+ 75.8
Leak current				
Sample A	7.5 μA	+60.0%	+ 33.4%	−54.7%
Sample B	4.2	+71.4	+142.9	+ 4.8

Listed values are the averaged values for five examined samples.

f) Chemical condensers (alminium electrode). Only one kind of commercially available chemical condensers was used to observe its characteristic changes under irradiation in detail. The measuring conditions of capacitance and tan δ were the same as used in the case with tantal electrode chemical condensers, while 450 V d.c. voltage was applied to the samples in the leak current measure-

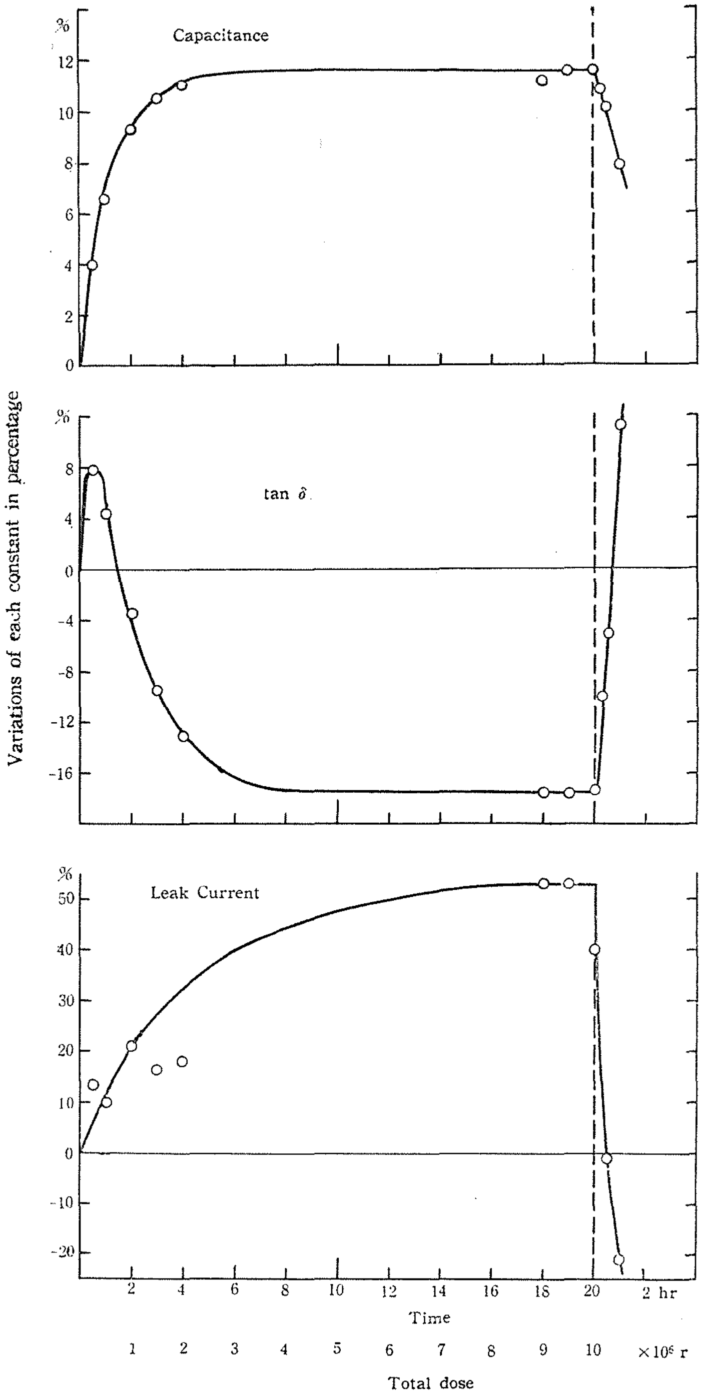

Fig. 1. For the chemical condensers variations induced by the gamma-ray irradiation in three constants, capacity, tan δ and leak current. At the right side from a dotted line the curves show the annealing processes at room temperature. The initial values before the irradiation are capacitance=10 μF, tanδ=140×10^{-4} and leak current=0.13 mA.

ment. Fig. 1 shows the result. The abscissa represents the total dose and lapse of time after the start of irradiation and the ordinate shows percentage of variation. Initial averaged values before the irradiation were 10 μF for capacitance, 140×10^{-4} for tan δ, and 0.13 mA for leak current. Capacitance increased rapidly with the irradiation and saturated after about 5 hours (2.5×10^{6} r), holding almost a constant value until a 10^{7} r irradiation. As soon as an irradiation started, tan δ increased rapidly to a maximum and then decreased to a saturated value which was lower than the initial. Leak current exhibited the tendency of gradual increase and saturation. This is remarkably different from the rapid decrease of insulation resistance in mica and ceramic condensers.

iii) Solid Diodes

Voltage-current characteristics of each sample was observed by the circuit with a cathode-ray oscilloscope, as shown in Fig. 2. Voltages applied to the samples were 100 V a.c. and 40 V d.c.

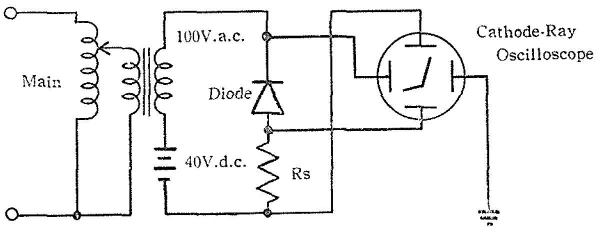

Fig. 2. Schematic diagram of observing the voltage-current characteristics of solid diodes.

By the irradiation of gamma rays the forward characteristics did not change, but slight changes in the backward were observed, since a backward current was so small compared with a forward current that the effect of carries produced by the irradiation became appreciable only in the backward characteristics. Fifty samples were tested but no breakdown and no extreme increase of the saturation current were observed. From this observation, the effect of gamma radiation on solid diodes scarcely influenced its rectifier characteristics.

iv) Transistors

At first, the test was performed using 45 lead wires (15 meter long), independently connected to the electrodes of 15 samples, to observe the change of characteristics under the irradiation, but the measurement failed because of the interference of cables. Therefore, the measurement under the irradiation was given up, and the annealing process of the effect observed four times before and after the irradiation, i.e. before irradiation, 30 minutes, 24 hours, and 240 hours after the irradiation at room temperature. The four elements of the H-matrix (h_{ie}, h_{fe}, h_{re}, h_{oe}) and I_{co} (collector current at an emitter input current is zero) were measured. Tables 7, 8 and 9 show the results. All the measured data listed are the averaged values for five same samples. Measuring conditions were common to all samples. For h-factors, E_{cb} (potential across collector and

Table 7. Variations of the power or L. F. transistors in the annealing process.

Measured constant	Before irrad.	After irrad.		
		30 min.	24 hr.	240 hr.
h_{ie}				
Sample A	1403Ω	− 7.1%	−21.3%	− 3.6%
Sample B	1432	−46.5	−48.3	−40.4
Sample C	2063	−49.6	−47.4	−39.7
Sample D	1664	−32.6	−27.0	−21.5
Sample E	2394	−28.4	−28.2	−21.4
Sample F	1658	− 3.6	−16.8	−13.6
Sample G	2488	−58.0	−50.6	−37.5
Sample H	1528	−24.0	−24.9	−17.9
Sample I	1086	−32.8	−35.2	−30.0
h_{fe}				
Sample A	48	−10.4%	−25.0%	− 8.3%
Sample B	52	−53.8	−55.8	−48.1
Sample C	72	−52.8	−50.0	−41.7
Sample D	59	−33.9	−27.1	−25.4
Sample E	74	−20.3	−29.7	−24.3
Sample F	41	−17.1	−19.5	−17.1
Sample G	77	−64.9	−57.1	−42.9
Sample H	40	−25.0	−25.0	−17.5
Sample I	35	−37.1	−40.0	−34.3
I_{co}				
Sample A	14.1 μA	+300.7%	+241.8%	+205.7%
Sample B	58.1	+106.2	+102.2	+ 84.9
Sample C	24.8	+123.4	+116.1	+ 92.7
Sample D	33.5	+ 49.0	+ 31.6	+ 30.4
Sample E	1.8	+500	+380	+310
Sample F	4.7	+ 66	+ 30	+ 13
Sample G	3.6	+150	+ 98	+ 70
Sample H	4.1	+ 7.3	+ 12	+ 0.5
Sample I	9.7	+100	+ 24	+ 25

Listed values are the averaged values for five examined samples.

base) = −6 V, I_e (emitter current) = 1 mA, and for I_{co}, $E_{cb}=-10$ V. The h-factors were measured by a transistor checker and I_{co} by a mico-ammeter. All samples of the group listed in the Table 7 showed similar tendencies, but A- and F-samples showed some differences from the others. From the observation of the annealing process at room temperature, none of all completely recovered 10 days after irradiation, however, all approached again to initial values. Concerning only with h_{ie}, samples in Table 8 could be divided into two groups, A, B, C and D, E, F. The former showed the tendency of returning to its initial value in the annealing process, but the sample E and F in the latter group showed an opposite tendency, gradual increase of the variation with time, nevertheless the

Table 8. Variations of the H. F. or I. F. transistors in the annealing process.

Measured constant	Before irrad.	After irrad.		
		30 min.	24 hr.	240 hr.
h_{ie}				
Sample A	1928Ω	− 12.3%	− 13.3%	− 11.3%
Sample B	1984	− 29.0	− 28.4	− 24.7
Sample C	2120	− 27.5	− 29.4	− 30.0
Sample D	698	+195.1	+175.8	+170.8
Sample E	366	+187.4	+183.6	+207.7
Sample F	650	+ 69.2	+ 94.3	+106.6
h_{fe}				
Sample A	59	− 5.1%	− 6.8%	− 5.1
Sample B	62	−33.9	−32.3	−29.0
Sample C	69	−30.4	−29.0	−30.4
Sample D	95	−24.2	−29.5	−32.6
Sample E	43	−23.3	−25.6	−18.6
Sample F	79	−54.4	−54.4	−48.1
I_{co}				
Sample A	0.7 μA	+220%	+220%	+200%
Sample B	3.5	+ 99	+120	+ 73
Sample C	6.4	+ 55	+ 4.7	+ 2.5
Sample D	0.8	+110	+ 76	+120
Sample E	0.9	+320	+310	+250
Sample F	2.7	+220	+330	+380

Listed values are the averaged values for five examined samples.

Table 9. Variations of the H. F. or convertor transistors in the annealing process.

Measured constant	Before irrad.	After irrad.		
		30 min.	24 hr.	240 hr.
h_{ie}				
Sample A	2320Ω	−17.6%	−17.5%	− 8.0%
Sample B	2972	−38.8	−37.6	−34.3
Sample C	2388	−14.0	+ 3.4	+22.3
Sample D	1828	−26.8	−23.1	−18.4
Sample E	1202	+ 0.5	− 0.3	+ 0.5
Sample F	3932	− 1.5	− 3.2	− 4.5
h_{fe}				
Sample A	74	−16.2%	−14.9%	− 4.1%
Sample B	116	−47.4	−47.4	−44.0
Sample C	89	0	− 2.2	− 3.4
Sample D	59	−30.5	−27.1	−22.0
Sample E	31	− 3.2	− 3.2	− 3.2
Sample F	150	− 2.0	− 4.0	− 4.0

I_{co}				
Sample A	0.8 μA	+480%	+380%	+220%
Sample B	1.0	+560	+370	+500
Sample C	2.0	+170	+130	+110
Sample D	1.0	+220	+120	+ 88
Sample E	0.7	+ 49	+ 36	+ 28
Sample F	0.6	+130	+ 92	+ 62

Listed values are the averaged values for five examined samples.

annealing processes of the effects by gamma radiation in h_{fe} and I_{co} were similar as a whole.

All samples in Table 9, with the exceptions of F in h_e and E in I_{co}, showed the similar annealing processes restoring damaged values to initial.

In the case of transistors it can be said that the changes of each factor did not arise from the effect of temperature increase caused by the irradiation but from only the effect of gamma rays, because all measurements were performed after the irradiation. From this result, it is concluded that the effect by the gamma irradiation of 10^7 r as a total did cause so large changes to each factor of transistors that the characteristics of the circuits employing these elements would change considerably when the system is used in an intense radiation field.

v) Magnetic Cores

Two kinds of samples, memory or switching cores and μ_0-cores, were tested. The effects of gamma radiation on the former were observed by drawing the B–H hysteresis loop on the cathode-ray oscilloscope with the circuit as shown in Fig. 3, while those on the latter by measuring the self-inductance of the coil

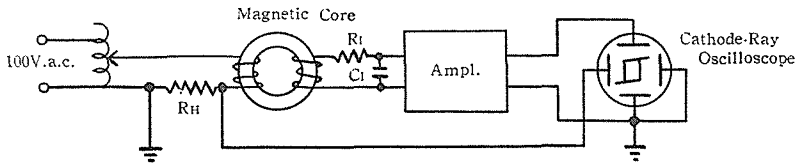

Fig. 3. Schematic diagram of observing the B–H hysteresis loop of memory and switching cores.

consisting of a μ_0-core in consideration. In this measurement a Q meter was used.

a) Memory or switching cores. One of two types in memory or switching cores exhibited no change by the gamma radiation, but the other considerably changed at the B–H loop by 10^7 r of the gamma irradiation as a total, however, did not change at the dose of about 10^6 r. After the irradiation these effects disappeared rapidly at room temperature.

b) μ_0-cores. Self-inductance of coils wound by the wire (0.2 mm diameter) on to the rings of the magnetic core were measured instead of initial permeability of cores. At the measurement, the true values of self-inductance of coils were obtained by substracting self-inductance of a cable used from measured values.

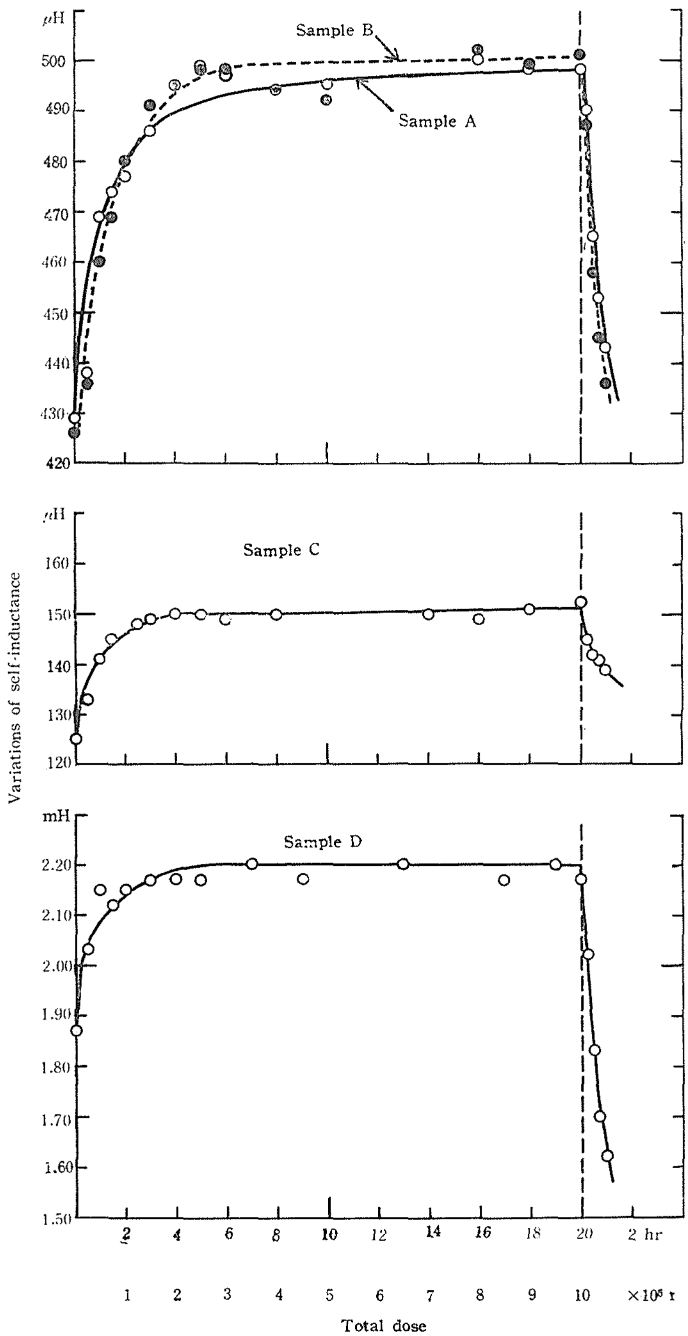

Fig. 4. Variations of self-inductances of coils, consisted from the μ_0-cores, induced by the gamma-ray irradiation. At the right side from a dotted line the curves show the annealing processes at room temperature.

Results are shown in Fig. 4. Changes of characteristics of all samples were quite alike and saturation was observed at $3\sim4\times10^6$ r. Curves in the right side of a dotted line at 10^7 r represent annealing processes after the irradiation. Since ferrite, a kind of solid solution made from bivalent metallic oxide and ferrous oxide, has a very complicated crystal structure, its magnetism appears as a difference between parallel and antiparallel magnetic moments existing in it. The change of magnetic moments by the lattice defects induced by gamma radiation seems to be responsible for the observed change of self-inductance.

DISCUSSION

Since the effects of gamma radiation on resistors are caused from electron-hole pairs produced by energetic photons, it is evident that the variation of resistance induced by gamma radiation for the carbon solid resistor is larger than that for the carbon film one. The interstitial atom displaced from a lattice site by gamma radiation tends to get back rapidly to an initial position after the irradiation at relatively high temperature. Also the decrease of insulation resistance for all kinds of condensers is due to the increase of carriers produced by the gamma radiation in dielectric materials. The decrease of dielectric constant and the increase of dielectric loss have been reported as the effect of the gamma radiation on dielectrics, however, in general these effects reported were measured after the irradiation. In the case of measurements during the irradiation as in the present experiment, the different result from measurements after the irradiation may be obtained because the spontaneous polarization would be increased due to positive or negative ion vacancies produced by the lattice defects and the influence from temperature increase and others would be superposed. The gamma-ray effects on the properties of the condenser as an electronic circuit component include not only that on dielectrics but that on electrodes made of alminium or other metals. Many papers concerning the radiation effects on semiconductors have been reported[2], however, most of these were the research on damage for intrinsic semiconductors and the effects on junction diodes and transistors have so far been scarcely reported.

Radiation effects on junction diodes are very important and interesting for the workers who are concerned with solid radiation detectors. Subsequent measurements of the current caused by electron-hole pairs produced by gamma radiation are now in progress. In the case of silicon junction diodes variation of current of 10^{-7} Amp. was obtained with the dose rate of 1.0×10^5 r/hr. To make our result more sure, it should be necessary to proceed further experiments by taking account of temperature change in the sample placed at the center of the cylindrical source cage. Our results with transistors are, of course, not so satisfactory that we are expecting to get better results by the experiments now in progress with some improved device and consideration. When these semiconductor elements are used in precise electronic instruments and radio transmitters or receivers employed in missiles and artificial satellites, the energetic particles such as cosmic rays may influence the properties of these electronic instruments.

The characteristics of electronic instruments used near the reactor may also be changed by the high energy radiation. By the present preliminary experiment seems that semiconductors are most sensitive of all kinds of electronic circuit components in the intense radiation field, and it can be concluded that the effects by the irradiation of 10^7 r as a total are not negligible for the precise electronic instruments. Further developments of researches with the irradiation of neutrons, electrons, protons and deutrons are now planning.

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