Technical Memorandum

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EFFECTS OF VIBRATION-AGING ON CERTAIN TYPES OF RECEIVING TUBES

by

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ABSTRACT

An experiment was conducted to determine the effects of vibration-aging on the reliability of a stock of miscellaneous receiving tubes.

A sample of 600 of each of seven types of receiving tubes was taken at random from stock. Each sample was divided into two groups of 300 each. One group was subjected to a 46 hour aging or burn-in, with power cycling, and vibration at 1g. The other group was used as a control.

Although more tubes failed in the vibration-aged groups than in the control groups, it was concluded that those surviving were no more reliable than those in the control groups. A possible explanation of this is that the vibration-aging introduced about as many potential defects as it eliminated. The principal conclusion was that the repetitive testing and rejection of defective tubes done on both groups was beneficial.

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EFFECTS OF VIBRATION-AGING ON CERTAIN TYPES OF RECEIVING TUBES

Introduction

The objective of this experiment was to determine whether the reliability of a stock of seven types of receiving tubes could be improved by a process of aging under conditions of vibration followed by a test to screen out the defective tubes. For the purposes of this experiment the reliability was measured by the percentage of defective tubes found on a MIL-E-1B test performed after the above procedure had been carried out. This of course does not necessarily evaluate accurately the reliability to be expected in service. However, our applications are generally such that the operating time required is very short. It may be, therefore, that the reliability measure used is not too bad for our type of use. For applications requiring longer service, a final test simulating longer use would be necessary, and the results might be different.

At the time the experiment was initiated, in the summer of 1953, a number of electronic equipment manufacturers had instituted various similar procedures but no conclusive determination of the merits of these procedures seemed to have been made. At least one experiment of this kind has since been carried out, and the results will be compared later with those reported here.

The general results found are that (1) no significant improvement in reliability can be attributed to the vibration-aging but (2) a significant improvement can be attributed to the screening effects of repeated testing. These results led to the decision not to use the vibration-aging procedure on the stock of tubes in question, but to set up a thorough inspection procedure. This consisted of a single test against the applicable MIL-E-1B specification. Additional, repetitive tests were not thought to be justified.

The processing and testing required for the experiment were carried out on a contract by Red Bank Division of Bendix Aviation Corporation.

The theory behind the proposal that vibration-aging followed by inspection might improve the reliability of the tubes is simple. Maintenance experience reported by military agencies has shown that the tube failure rate in electronic gear is higher in the first 50 hours or so of regular service than it is for the next few hundred hours. (This statement applies to tubes which did not receive the 50-hour "stabilization" now used by most tube manufacturers for "reliable" tubes.) Although we are not interested in hundreds of hours of service, it was thought that a procedure which simulated the initial equipment service might weed out most of the incipient failures and result in a lower failure rate for short-time service thereafter.

Plan of Experiment

The experimental plan is outlined in Table I. Samples of 600 tubes of each of seven types were taken at random from stock. Each group of 600 tubes was divided into two lots of 300 each; one was designated as the "experimental lot", the other as the "control lot". The stock consisted of tubes supplied by several manufacturers at various times. It was not practical to sample each manufacturer's product in proper proportion. It was determined by significance tests, after the first test, that the experimental and control lots did not differ significantly in quality.

It can be seen from Table I that the only difference between the treatment of the experimental and control lots lies in the first process. The experimental lot received 46 hours of vibration-aging; the control lot spent an equal time on the shelf. The 1G level of vibration was arbitrarily selected. It was thought that this level is not severe enough to damage properly made tubes. On the other hand, it was conjectured that it is severe enough to accelerate the failure of poorly made tubes. Such defects as poor welds, poor insulation of heaters, insufficient inter-element clearances, and the presence of unwanted material in the tubes would be likely in poorly made tubes.

After each test, the rejected tubes were discarded and were not replaced. Consequently, the number of tubes in each lot decreased as the experiment proceeded.

Detailed Results

The results are given in Tables II - VI. Table II includes the test results for each of the seven tube types. The percentages of defective tubes found on each test after the first test have been figured on the basis of the number of tubes coming up for the test; not on the basis of the original 300 tubes in each lot. The applicable MIL-E-1B test specifications were used, with the additional requirement added that there must be no intermittent opens or shorts during vibration. The causes for rejection have been grouped into three classes: (1) inoperative due to shorts and/or opens, (2) operative but outside specification limits, and (3) inoperative due to breakage. Tubes rejected because of (3) have been ignored as having no significance in the experiment. This was based on the fact that most of the breakage was due to handling rather than to the conditions simulating normal service.

It can be seen that rather large percentages were rejected on the first test. This should not be charged entirely against the tube manufacturers since the test requirements applied were generally more severe than those against which the tubes were originally purchased. However, they were not more severe than the application requires.

Tables III, IV, and VI show the results of an analysis of the statistical significance of the data made by Mr. C. R. Clark, 5131-1. The details of the methods used are given in an informal memorandum by Mr. Clark dated October 27, 1954, entitled, "Data from Red Bank Vibration-Aging Tube Test", filed Case 435.03. The results of this analysis come out in terms of the probability that an observed apparent reduction in the fraction defective is due to chance. In order to convert these results into words, the following arbitrary interpretation was established:

<u>Probability of Chance</u>	<u>Significant?</u>
<1%	Yes
1-10%	Possibly
>10%	No

Table III shows the results found on the third test, comparing the experimental and control lots. No significant difference attributable to the special treatment given the experimental lot is revealed, except for a "possibility" in the cases of the 5670, TD-9, and 6X4 types. This possibility is confined to the out-of-limits category of defects. As far as inoperatives are concerned, no significant difference appeared.

Table IV shows the results of comparing the fraction defective found on the first and third tests. This is a measure of how effective the first two tests were in screening out defective tubes. The results from both the experimental and the control lots were included since the analysis of Table II showed no significant difference between them. The results show that the fraction defective found on the third test is significantly less than on the first test in several cases. In addition, there are several cases where the improvement is "possibly" significant. This is true of inoperatives as well as out-of-limit tubes, although there are fewer "yes" cases and more "possibly" entries under the inoperative heading.

Table V shows the average characteristics for the tubes passing all three tests. The changes observed are not believed to be significant. There is no indication that the vibration-aging caused any substantial shift in the characteristics.

Table VI shows the results of a special experiment added for two of the types. This consisted of operating all of the tubes surviving the third test 46 hours with 2.5G vibration and cycled operating voltages. The purpose was to determine whether the treatment given the experimental lots during the first process (46 hours at 1G, tubes operating) resulted in a product which would stand up better under simulated conditions of use. The statistical analysis of the fractions defective on the final test (includes failures during 46-hour run) shows no significant improvement for type 5654, and "possibly" for type 6AQ5 on "out-of-limits" only.

Conclusions

We draw the following conclusions from this experiment:

- (1) The reliability of the stock of tubes sampled would not be significantly improved by 46 hours of aging at 1G followed by a regular test, beyond the screening effect of the test alone.
- (2) Two regular successive tests reduce the fraction defective found on a third test as determined by comparing the fraction defective found on the first test with the fraction defective found on the third test.
- (3) No significant shift in tube characteristics could be attributed to the vibration-aging.

It is presumed that the lack of improvement in reliability attributable to the vibration-aging means that the process adds about as many incipient defects as it eliminates.

It should be understood that the conclusions reached here apply only to the particular stock of tubes sampled. Tubes of later design, or tubes manufactured under different conditions, might show quite different results.

A paper entitled "Electron Tube Aging" by Mr. R. S. Whitlock of Wright Air Development Center describes a similar experiment. The general results with regard to the effects of the vibration-aging were the same as those reported here. However, he found that the experimental lots contained no more defective tubes after the vibration-aging than did the control lots. In our experiment, the experimental lots contained more defective tubes on the second test than did the control lots.

The assistance of personnel in Departments 5420 and 5510 of the Sandia Corporation in the planning of this experiment is gratefully acknowledged. The assistance of engineering personnel at the Kansas City and Red Bank Divisions of Bendix Aviation Corporation is also acknowledged.

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TABLE I

Plan of Vibration-Aging Experiment

<u>Steps</u>	<u>Experimental Lot</u>	<u>Control Lot</u>
*First Test	MIL-E-1B	MIL-E-1B
First Process	/Vibr.-age 46 hrs.	Store 46 hrs.
*Second Test	MIL-E-1B	MIL-E-1B
Second Process	Store 24 hrs.	Store 24 Hrs.
Third Test	MIL-E-1B	MIL-E-1B

*After each of these tests, the tubes which had failed to meet the requirements of the applicable MIL-E-1B test specification were discarded.

/This aging was done with the tubes vibrating at 1G. Normal operating voltages were applied to the tubes on a cycle of 50 minutes on, 10 minutes off.

TABLE II(a)

Red Bank Experiment Results, Type 5654Percentages, Based on Numbers in Parentheses

	FIRST TEST		SECOND TEST		THIRD TEST	
	Control	Experimental	Control	Experimental	Control	Experimental
	<u>Lot</u> (300)	<u>Lot</u> (300)	<u>Lot</u> (251)	<u>Lot</u> (244)	<u>Lot</u> (246)	<u>Lot</u> (207)
INOPERATIVE	0.3	0.3	0.0	2.9	1.2	2.4
OUT OF LIMITS	15.3	17.4	1.6	10.2	3.3	2.4
TOTALS	15.6	17.7	1.6	13.1	4.5	4.8
BROKEN	0.7	1.0	0.4	2.0	0.8	1.9

TABLE II(b)

Fed Bank Experiment Results, Type 5670Percentages, based on Numbers in Parentheses

	<u>FIRST TEST</u>		<u>SECOND TEST</u>		<u>THIRD TEST</u>	
	<u>Control Lot</u>	<u>Experimental Lot</u>	<u>Control Lot</u>	<u>Experimental Lot</u>	<u>Control Lot</u>	<u>Experimental Lot</u>
	(300)	(300)	(275)	(275)	(269)	(267)
INOPERATIVE	1.7	0.3	0.4	1.1	0.4	0.0
OUT OF LIMITS	6.0	6.0	1.1	1.5	1.8	0.4
TOTALS	7.7	6.3	1.5	2.6	2.2	0.4
BROKEN	0.7	2.0	0.7	0.4	0.7	1.1

TABLE II(c)

Red Bank Experiment Results, Type TD-9Percentages, Based on Numbers in Parentheses

	<u>FIRST TEST</u>		<u>SECOND TEST</u>		<u>THIRD TEST</u>	
	<u>Control Lot</u>	<u>Experimental Lot</u>	<u>Control Lot</u>	<u>Experimental Lot</u>	<u>Control Lot</u>	<u>Experimental Lot</u>
	(300)	(300)	(224)	(218)	(211)	(191)
INOPERATIVE	2.0	2.7	0.0	0.9	0.0	0.0
OUT OF LIMITS	23.3	24.6	4.5	5.1	1.9	0.0
TOTALS	25.3	27.3	4.5	6.0	1.9	0.0
BROKEN	0.0	0.0	1.3	6.4	0.0	0.0

TABLE II(d)

Red Bank Experiment Results, Type 6X-4Percentages, Based on Numbers in Parentheses

	<u>FIRST TEST</u>		<u>SECOND TEST</u>		<u>THIRD TEST</u>	
	<u>Control Lot</u>	<u>Experimental Lot</u>	<u>Control Lot</u>	<u>Experimental Lot</u>	<u>Control Lot</u>	<u>Experimental Lot</u>
	(300)	(300)	(265)	(276)	(259)	(263)
INOPERATIVE	4.0	1.3	0.0	0.7	0.0	0.0
OUT OF LIMITS	6.7	6.7	2.3	4.0	2.7	0.8
TOTALS	10.7	8.0	2.3	4.7	2.7	0.8
BROKEN	1.0	0.0	0.0	0.0	0.4	0.0

TABLE II(e)

Red Bank Experiment Results, Type 5903Percentages, Based on Numbers in Parentheses

	<u>FIRST TEST</u>		<u>SECOND TEST</u>		<u>THIRD TEST</u>	
	<u>Control Lot</u>	<u>Experimental Lot</u>	<u>Control Lot</u>	<u>Experimental Lot</u>	<u>Control Lot</u>	<u>Experimental Lot</u>
	(300)	(300)	(285)	(289)	(280)	(284)
INOPERATIVE	1.3	1.7	0.7	1.0	0.0	0.0
OUT OF LIMITS	3.4	1.3	0.4	0.3	0.0	0.35
TOTALS	4.7	3.0	1.1	1.3	0.0	0.35
BROKEN	0.3	0.7	0.7	0.3	0.0	0.0

TABLE II(f)

Red Bank Experiment Results, Type 12AT7Percentages, Based on Numbers in Parentheses

	<u>FIRST TEST</u>		<u>SECOND TEST</u>		<u>THIRD TEST</u>	
	<u>Control Lot</u>	<u>Experimental Lot</u>	<u>Control Lot</u>	<u>Experimental Lot</u>	<u>Control Lot</u>	<u>Experimental Lot</u>
	(300)	(300)	(251)	(241)	(241)	(210)
INOPERATIVE	1.0	1.0	0.0	0.0	0.4	0.0
OUT OF LIMITS	14.6	18.6	1.6	7.1	2.0	1.9
TOTALS	15.6	19.6	1.6	7.1	2.4	1.9
BROKEN	0.7	0.0	2.4	5.8	3.3	1.0

TABLE II(g)

Red Bank Experiment Results, Type 6AQ5Percentages, Based on Numbers in Parentheses

	FIRST TEST		SECOND TEST		THIRD TEST	
	Control	Experimental	Control	Experimental	Control	Experimental
	<u>Lot</u> <u>(300)</u>	<u>Lot</u> <u>(300)</u>	<u>Lot</u> <u>(239)</u>	<u>Lot</u> <u>(253)</u>	<u>Lot</u> <u>(219)</u>	<u>Lot</u> <u>(193)</u>
INOPERATIVE	1.3	3.7	2.1	2.4	0.9	1.0
OUT OF LIMITS	17.3	10.7	5.4	18.6	1.4	3.1
TOTALS	18.6	14.4	7.5	21.0	2.3	4.1
BROKEN	1.7	1.3	0.8	2.8	2.3	2.1

TABLE III

Summary of Vibration-Aging Results
Significance of Reduction in Fraction Defective
in Experimental Lots Compared to Control Lots on Third Test

<u>Tube Type</u>	<u>Inoperatives</u>	<u>Out-of-Limits</u>	<u>Total Defective</u>
5654	No	No	No
5670	"	"	Possibly
TD-9	"	Possibly	"
6X4	"	"	"
5903	"	No	No
12AT7	"	"	"
6AQ5	"	"	"

NOTE

Meaning of words entered in table is as follows:

<u>Probability of Chance</u>	<u>Significant?</u>
< 1%	Yes
1 - 10%	Possibly
> 10%	No

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TABLE IV

Summary of Screening Results

Significance of Reduction in Fraction Defective
in Third Tests Compared to First Tests

<u>Tube Type</u>	<u>Inoperatives</u>		<u>Out-of-Limits</u>		<u>Total Defectives</u>	
	<u>Control</u>	<u>Exp.</u>	<u>Control</u>	<u>Exp.</u>	<u>Control</u>	<u>Exp.</u>
5654	No	*Possibly	Yes	Yes	Yes	Yes
5670	"	No	Possibly	"	"	"
TD-9	Possibly	Possibly	Yes	"	"	"
6X4	Yes	"	Possibly	"	"	"
903	Possibly	"	Yes	Possibly	"	Possibly
12AT7	No	No	"	Yes	"	Yes
6AQ5	"	Possibly	"	"	"	"

*Possibly an increase in fraction defective.

NOTE

Meaning of words entered in table is as follows:

Probability of Chance Significant?

< 1%	Yes
1 - 10%	Possibly
>10%	No

TABLE V(a)

Average Characteristics, Type 5654

	FIRST TEST		SECOND TEST		THIRD TEST	
	<u>Control Lot</u>	<u>Exp Lot</u>	<u>Control Lot</u>	<u>Exp Lot</u>	<u>Control Lot</u>	<u>Exp Lot</u>
Heater Current (MA)	176	176	175	175	175	175
Plate Current (MA)	8.7	8.8	8.6	8.6	8.1	8.7
Transconductance (u mhos)	5304	5290	5263	5268	5288	5329
Vibration Noise (MV)	39	44	27	28	35	37

TABLE V(b)

Average Characteristics, Type 5670

	FIRST TEST		SECOND TEST		THIRD TEST	
	<u>Control Lot</u>	<u>Exp Lot</u>	<u>Control Lot</u>	<u>Exp Lot</u>	<u>Control Lot</u>	<u>Exp Lot</u>
Heater Current (MA)	355	353	353	352	354	353
Plate Current ₁ (MA)	7.8	7.8	8.0	7.9	8.0	7.8
Transconductance ₁ (u mhos)	5209	5150	5300	5213	5339	5259
Plate Current ₂ (MA)	7.6	7.5	7.8	7.6	7.8	7.6
Transconductance ₂ (u mhos)	5227	5172	5277	5218	5336	5242
Vibration Noise (MV)	54	53	29	32	30	38

TABLE V(c)

Average Characteristics, Type TD-9

	FIRST TEST		SECOND TEST		THIRD TEST	
	<u>Control Lot</u>	<u>Exp Lot</u>	<u>Control Lot</u>	<u>Exp Lot</u>	<u>Control Lot</u>	<u>Exp Lot</u>
*Ionization Voltage	147	146	147	146	147	146
**Plate Voltage	148	147	148	147	148	149
***Regulation	3.4	3.3	2.7	2.1	2.6	2.1

* $R_p/I_b = 75$ to 400 uA

** $R_p/I_b = 250 \text{ uA}$

*** E_b for $I_B = 400 \text{ uA}$ minus E_b for $I_B = 7.5 \text{ uA}$

TABLE V(d)

Average Characteristics, Type 6X4

	FIRST TEST		SECOND TEST		THIRD TEST	
	<u>Control Lot</u>	<u>Exp Lot</u>	<u>Control Lot</u>	<u>Exp Lot</u>	<u>Control Lot</u>	<u>Exp Lot</u>
Heater Current (MA)	615	621	617	624	617	623
Rectified Current (MA)	75	75	77	78	77	78
H-K Leakage (uA)	7.8	7.5	6.7	8.2	7.2	7.9

TABLE V(e)

Average Characteristics, Type 5903

	FIRST TEST		SECOND TEST		THIRD TEST	
	<u>Control Lot</u>	<u>Exp Lot</u>	<u>Control Lot</u>	<u>Exp Lot</u>	<u>Control Lot</u>	<u>Exp Lot</u>
Heater Current (MA)	73	73	73	74	73	74
Rectified Current (MA)	18.5	18.6	18.6	18.0	18.0	18.0
H-K Leakage (uA)	2.9	3.6	1.7	1.5	1.7	1.5

TABLE V(f)

Average Characteristics, Type 12AT7

	FIRST TEST		SECOND TEST		THIRD TEST	
	<u>Control Lot</u>	<u>Exp. Lot</u>	<u>Control Lot</u>	<u>Exp Lot</u>	<u>Control Lot</u>	<u>Exp Lot</u>
Heater Current (MA)	152	151	152	152	151	151
Plate Current ₁ (MA)	11.6	10.9	11.1	10.4	11.1	10.4
Transconductance ₁ (u mhos)	5123	5025	5107	4883	5082	4917
Plate Current ₂ (MA)	11.5	10.8	11.1	10.4	11.1	10.4
Transconductance ₂ (u mhos)	5288	5174	5275	5063	5235	5035
Vibration Noise (MV)	37	25	36	29	39	30

TABLE V(g)

Average Characteristics, Type 6AQ5

	FIRST TEST		SECOND TEST		THIRD TEST	
	<u>Control Lot</u>	<u>Exp Lot</u>	<u>Control Lot</u>	<u>Exp Lot</u>	<u>Control Lot</u>	<u>Exp Lot</u>
Heater Current (MA)	456	453	448	454	450	453
Plate Current (MA)	48	47	47	45	47	46
Output Voltage (V)	155	155	151	150	154	153
Vibration Noise (MV)	56	70	52	62	63	75

TABLE VI

Test Results after 46 Hours *Simulated UsePercentages Defective

	<u>Control Lot</u>	<u>Exp. Lot</u>
<u>Type 5654</u>		
Inoperative	1.7	/ 0.5
Out of Limits	1.7	2.6
Total Defective	3.4	/ 3.1
 <u>Type 6AQ5</u>		
Inoperative	1.4	/ 0.0
Out of Limits	12.4	// 7.7
Total Defective	13.8	// 7.7

*46 hours vibration at 2.5G with power cycled 50 minutes on, 10 minutes off.

~~/~~Not significantly better than control lot.

~~//~~Possibly significantly better than control lot.