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AXIAL COMPRESSION TESTING OF VACUUM TUBE GLASS-CERAMIC/MOLYBDENUM FRAMES

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ABSTRACT

The strength of a vacuum tube subassembly is affected by many factors, including the subassembly design, the process used to bond the parts, and the type of equipment used to measure the strength. In this study, these variables were examined for a subassembly consisting of a molybdenum sleeve, a glass-ceramic insulator, and a molybdenum cylindrical frame. Results showed that compression testing of different designs ranged from 765 to 3170 pounds. No difference appeared in the strength of subassemblies due to variations in selected steps in processing. A self-aligning compression test fixture resulted in higher strength readings than those obtained with conventional fixturing.

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INTRODUCTION

Axial compression testing of vacuum tube glass-ceramic insulator/molybdenum frame assemblies discriminates between processing parameters that affect the strength of the glass-ceramic and the strength of the insulator-molybdenum cylinder bond.[1] Figures 1 and 2 are schematic drawings of typical vacuum tube frame assemblies built and tested at the General Electric Neutron Devices Department (GEND). This paper reports on axial compression testing to evaluate design geometries and process conditions.

One of the processes examined involves the effect of molybdenum surface preparation on glass-ceramic/molybdenum seal strength. Results of the evaluation described in Reference 1 indicated that assemblies having acid-etched molybdenum cylinders withheld a greater load than assemblies not having acid-etched molybdenum parts. (Table 1 is a summary of the results of that study.) The mode of failure for test results in Table 1 consisted of the ultimate load the part could withstand as opposed to the first crack load (as determined by audible means or acoustical emission). Unless otherwise stated, the test results in the present study consist of the ultimate load.

Table 1. Summary of Load Tests, Subassemblies I and II

Molybdenum Part Treatment	Subassembly	Insulator Condition	Quantity Tested	Failure* Load ($\bar{X}$) (lb)
	I	As-Sealed	24	840
Not Acid Etched	II, Unannealed	HF Etched	9	1128
	II, Annealed	HF Etched	3	1143
	I	As-Sealed	3	1596
Acid Etched	I	Insulator Vapor Honed	3	543
	I	Insulator Acid Etched	3	1446

*Ultimate load the assembly could withstand

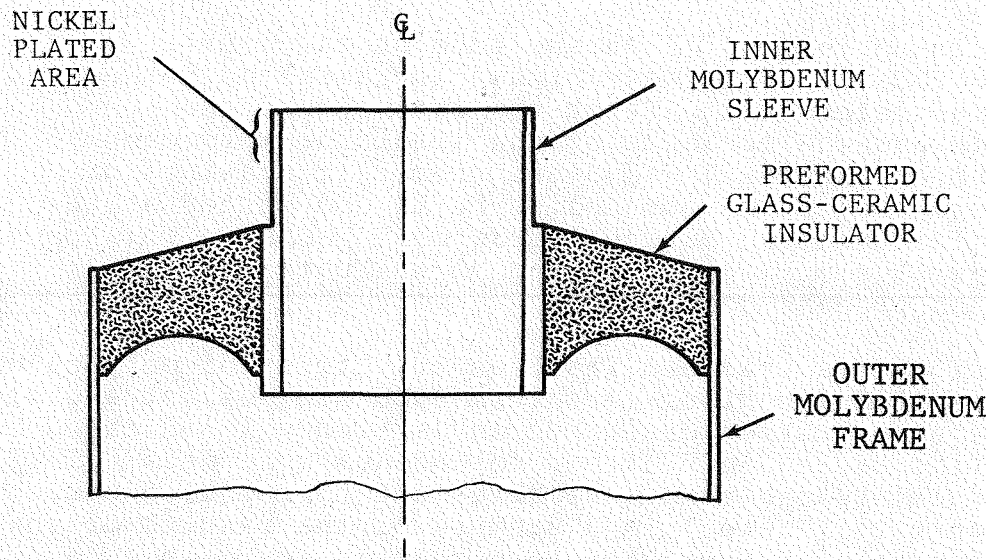


Figure 1. Frame Subassembly I

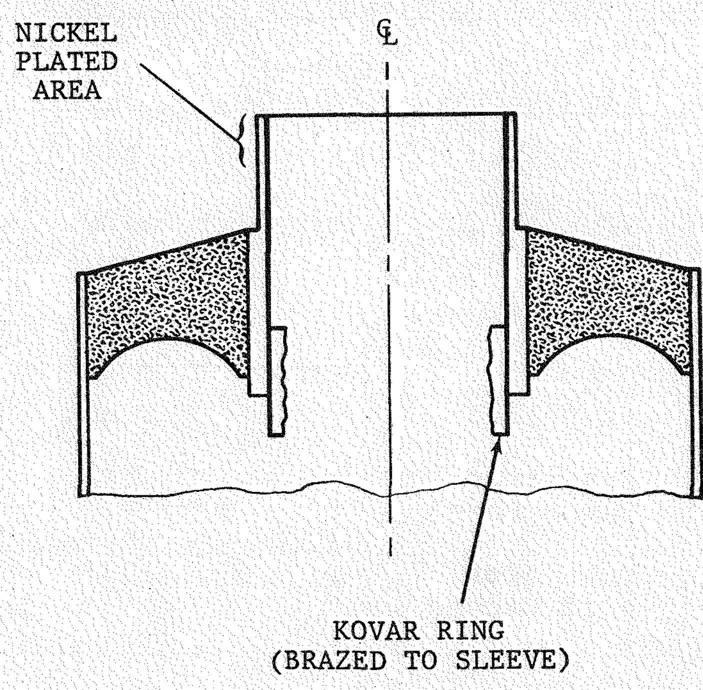


Figure 2. Frame Subassembly II

This paper reports the results of evaluating:

a. Five frame designs;

b. Self-aligning axial compression fixture;

c. Na_2CO_3 - blasted insulators.

FRAME DESIGNS

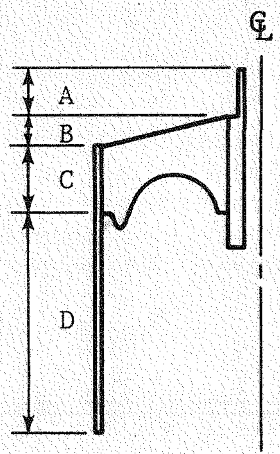
The five frame designs tested are shown in Figure 3. These are identified as M4N through M8N designs.

M4N DESIGN VERSUS M5N DESIGN

Four M4N and six M5N MC2980 subassemblies were tested. These frames were fabricated at the Sandia National Laboratories, Albuquerque, New Mexico (SNLA) physical electronics shop in a Brew furnace using a glass-ceramic with the composition shown in Table 2. In all cases, retainer rings on the upper portion of the frames were used during sealing. The heat-up rate (after the 450°C hold) was 20°C/min and the sealing weight was 500 g. The molybdenum parts were prepared by boiling KOH rinsing, chromic acid rinsing, acid-etching, chromic acid rinsing and nickel plating in the braze regions. The insulators were not acid-etched after sealing. These parts were compression loaded by placement between the platens of a universal tensile test machine.

Table 2. Glass-Ceramic Composition

Compound	Weight Percent
Al_2O_3	9.5
BaO	4.8
Na_2O	4.8
P_2O_5	2.5
SiO_2	46.2
ZnO	32.2



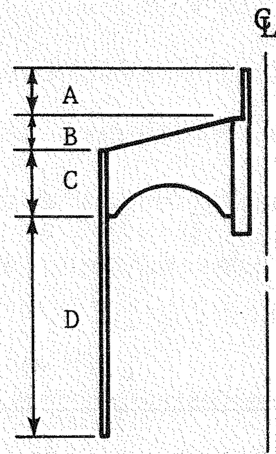
M4N Design

A = ∿ 0.330

B = ∿ 0.174

C = ∿ 0.400

D = ∿ 1.324



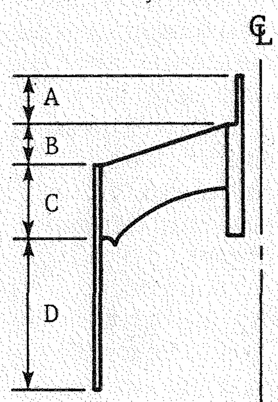
M5N Design

A = ∿ 0.330 in.

B = ∿ 0.174 in.

C = ∿ 0.400 in.

D = ∿ 1.324 in.



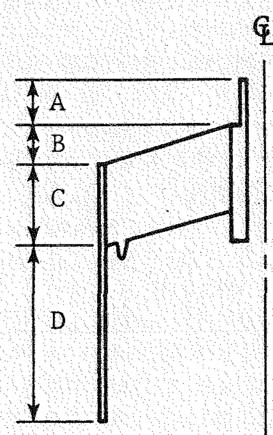
M6N Design

A = ∿ .330 in.

B = ∿ .120 in.

C = ∿ .377 in.

D = ∿ 1.293 in.



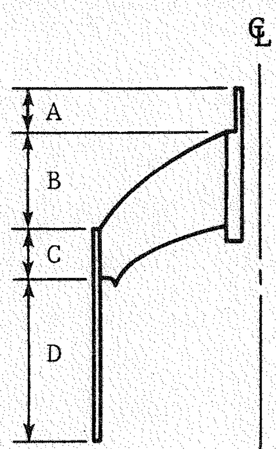
M7N Design

A = ∿ .330 in.

B = ∿ .130 in.

C = ∿ .572 in.

D = ∿ 1.098 in.



M8N Design

A = ∿ .330 in.

B = ∿ .210 in.

C = ∿ .523 in.

D = ∿ 1.147 in.

Figure 3. Frame Designs

Results

Although the number of test samples was limited, there was a significant difference between the load carrying capability of the M4N versus M5N design (1215 versus 786 lb) with the M4N being superior. The results for this test are shown in Table 3. There was considerable scatter (and some overlap) in the results. The range for M4N frames was 460 lb (or 37 percent of $\bar{X}$) while for the M5N design the range was 350 lb (or 44 percent of $\bar{X}$). The M5N results are among the lowest recorded using this testing method (only the vapor honed parts of previous tests,[1] with $\bar{X}$ = 543 lb, was lower). Since these parts had acid-etched molybdenum piece parts, the benefit of acid etching is questioned. However, after acid etching of the molybdenum, the parts were nickel plated in the braze regions. This extra handling or processing may have provided some surface contamination that perhaps degraded the interface strength. These parts were sealed using a heat-up rate of 20°C/min rather than 40°C/min as is commonly done. There is some indication that this may have caused a reduction in strength. All failures initiated at the inner sleeve-insulator interface at an area of the interface near the inside of the tube envelope.

Table 3. Ultimate Compression Load Applied to SNLA-Supplied M4N and M5N Subassemblies

Frame Number	Design	Ultimate Load (lb)	$\bar{X}$ and Range (lb)
AA-1247	M4N	1120	
1258	M4N	1350	$\bar{X}$ = 1215
1249	M4N	1500	Range = 460
1253	M4N	890	
AA-1249	M5N	950	
1253	M5N	890	$\bar{X}$ = 786
1227	M5N	680	Range = 350
1222	M5N	765	
1225	M5N	1000	
1226	M5N	650	

EVALUATION OF M6N, M7N AND M8N DESIGNS

The molybdenum cylinders for these assemblies were treated the same as the molybdenum for the M4N and M5N evaluation. The insulators were not acid etched after sealing. Testing consisted of placement of the parts between the platens of a universal tensile testing machine.

Results

The three parts tested showed excellent load-carrying capacity as can be seen in Table 4. The strength of the M8N was extremely high (3170 lb). At failure it essentially shattered leaving small bits of glass-ceramic along with an inner sleeve and a cracked outer sleeve. A crack was detected (by Zyglo*) in the insulator of the M6N design prior to testing. Even though the insulator was cracked, the unit withheld 1706 lb.

Table 4. Ultimate Compression Loads Applied to M6N, M7N and M8N Subassemblies

Design	Ultimate Load (lb)
M8N	3170
M7N	1610
M6N	1706

*Trademark, Magnaflux Corp.

EVALUATION OF THE METALLURGY AND CERAMICS LABORATORY SELF-ALIGNING FIXTURE

For this test, ten units were selected from a group of subassemblies that had been shocked by thermal cycling. The thermal cycling test was performed by immersing the parts first in boiling water and then in an acetone-dry ice mix. Five parts were compression loaded by placement between the platens of a universal tensile testing machine and five were loaded by placement in a self-aligning compression test fixture. The loading rate was 0.05 in./min.

RESULTS

This study showed that the ultimate compression strength results are increased substantially by use of the compression test fixture. The reason is apparently due to the fact that stresses are more uniformly distributed. The results (Table 5) show that X for those parts tested in the self-aligning fixture was 1556 lb with a range of 380 lb (or 22 percent of X), while X of those tested by placement of the part between the testing machine platens was 993 lb with a range of 820 lb (or 82 percent of X).

PRELIMINARY STUDY OF Na_2CO_3-BLASTED INSULATORS

A preliminary evaluation of Na_2CO_3-blasted insulators was performed to determine whether or not a large reduction in ultimate compression strength existed. Five subassemblies, the insulators of which had been Na_2CO_3 blasted for the purpose of cleaning the residual graphite from the insulator surface, were tested. The molybdenum parts were not acid etched. The assemblies were evaluated in the compression loading fixture at a loading rate of 0.05 in./min.

RESULTS

From this study, an X of 1555 lb with a range of 110 lb (or 7 percent of X) was determined. This X is quite high for frames which had unetched molybdenum parts. Results for these tests are shown in Table 6.

Table 5. Ultimate Compression Load Tests of Subassembly I's Tested by Either the Self-Aligning Fixture or Conventional Fixturing

Test Equipment	Unit No.	Ultimate Load (lb)	$\bar{X}$ and Range (lb)
Self-Aligning Fixture	1	1680	$\bar{X}$ = 1556
	2	1730	Range = 380
	3	1545	
	4	1350	
	5	1475	
Conventional Fixturing	1	955	$\bar{X}$ = 993
	2	1120	Range = 820
	3	1455	
	4	635	
	5	800	

Table 6. Ultimate Compression Load Applied to Subassembly I's in Which the Insulators were Na_2CO_3 Blasted

Unit Number	Load at 1st Crack* (lb)	Ultimate Compressive Strength (lb)	$\bar{X}$ and Range (lb)
1	607	1500	$\bar{X}$ = 1555
2	510	1610	
3	608	1520	Range = 110
4	620	1560	
5	652	1585	

*Detectable by audible sound. This phase of the testing was performed by placement of the subassembly I between the platens of the universal testing machine while the ultimate compression strength was determined using the self-aligning fixture.

FOLLOW-UP EVALUATION OF Na_2CO_3-BLASTED VERSUS AS-SEALED SUBASSEMBLY I INSULATORS

A total of 20 units were evaluated. These parts were rejected for visual defects or for failure at ultrasonic inspection. The approximate location of the flaw is shown in Table 7. The molybdenum surfaces were not acid etched. Ten units were tested in the as-sealed state while the remaining ten had insulators cleaned by Na_2CO_3 blasting. Testing was performed using the compression loading fixture at a loading rate of 0.05 in./min. An acoustic emission technique, which was used to monitor the initial crack formation, was performed by resting a phonograph needle (with cartridge) against the frame during loading. Its output versus load was measured.

Table 7. Comparison of Ultimate Compression Load Applied to Subassemblies With Cleaned and Non-Cleaned Insulators

Condition	Unit No.	First Pick-Up (lb)	Ultimate Compression Strength (lb)	Location of Ultrasonic Flaws
As Sealed - No Cleaning	1	1080	1735	Outer
	2	1450	1565	None
	3	1000	1610	Inner and Outer
	4	1360	1620	Outer
	5	1240	1555	Inner
	6	1300	1525	Inner and Outer
	7	140*	670*	Inner and Outer
	8	1210	1565	Inner and Outer
	9	695*	695*	Outer
	10	1620	1915	Inner and Outer
		$\bar{X}$ = 1282	$\bar{X}$ = 1636	
		Range = 620	Range = 350	
Sodium Carbonate Cleaned	1	800	1550	Inner
	2	615	1495	Outer
	3	1500	1705	Outer
	4	1625	1675	Outer
	5	1460	1515	Inner
	6	1180	1490	Outer
	7	960	1590	Outer
	8	1030	1565	Inner
	9	1100	1570	Outer
	10	1300	1605	Inner
		$\bar{X}$ = 1157	$\bar{X}$ = 1576	
		Range = 845	Range = 215	

*Not used in computing $\bar{X}$ and range.

RESULTS

No significant difference was noted between $\bar{X}$ of subassembly I's tested with the Na_2CO_3-blasted insulators (1576 lb) as opposed to those having as-sealed insulators (1636 lb). As with samples tested in the preliminary study, the values are quite high for molybdenum parts that were not acid etched. The significance of the initial crack detection as determined by acoustical emission is not specifically known. However, for these groups of frames the first crack-detectable results are about the same (1157 lb for Na_2CO_3 blasted versus 1282 lb for as-sealed). It is interesting that the first audible crack for the test in the preliminary study averaged 599 lb, or considerably lower than the values determined in this test by acoustical emission. Since there is no significant difference in the ultimate compressive strength of frames in this study and the previous one, it could be assumed that their initial crack indications should be about the same. The difference then must be attributed to differences in test fixturing since the study used the self-aligning fixture for the initial crack determination while the previous study did not. The results of the evaluation are shown in Table 6.

CONCLUSIONS

From these results it is quite evident that the self-alignment fixture increased the results obtainable by axial compression testing. Not only did the average value ($\bar{X}$) increase, but the data scatter was reduced.

A question arises as to the effect of acid etching on the molybdenum piece parts. The previous study[1] indicated that frames with acid-etched molybdenum parts had a higher ultimate compression load than those frames with unetched molybdenum parts (1596 versus 840 lb). However, frames having acid-etched molybdenum cylinders and tested with the self-alignment fixtures were capable of withholding a substantial load (approximately 1500 lb). It may be an effect due to molybdenum surface preparation or it may be due to the fact that those parts and assemblies have more parallel surfaces than the lesser testing assemblies. When testing by placement between the platens of the test machine, unparallel surfaces would be a significant factor that would not be present on units tested in the self-alignment compression fixture.

ACKNOWLEDGMENTS

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REFERENCE

1. R. K. Spears, "Structural Integrity Testing of Glass-Ceramic/Molybdenum Vacuum Tube Frames," GEND Report GEPP-TIS-502, April 1980, NTIS, U. S. Department of Commerce, Springfield, Virginia.

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