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STUDY OF THE PARAMETERS AFFECTING CONTACT PERFORMANCE OF HIGH RELIABILITY RELAYS

By Charles P. Nunn and S. Bradford McRickard

September, 1969

Prepared Under Contract No. NAS 12-634 by
DEUTSCH RELAY DIVISION
E. Northport, New York

For The Electronic Research Center

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

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SUMMARY

This study was directed towards the process, contamination, and contact material parameters that are known to affect the electrical contact performance of high reliability, crystal-can type relays. The study was built around the "sealed switching module" contact system which, by virtue of its design, eliminated the gross effects of the coil assembly from the contacts, thereby providing an organic free contact module.

A fundamental failure mechanism was found on the gold plated, silver substrate contact system when operated under extremely dry conditions. Cold welding of the contacts would occur after 30,000 operations due to mechanical wear through the gold plate and exposure of the soft silver-palladium alloy substrate material. This basic material failure mode was eliminated by the introduction of a 2-5 micron, electroplated rhodium contact system.

The influence of vacuum outgassing parameters on low temperature performance was determined. It was found that water vapor concentrations in excess of 1,000 ppm would cause erratic contact resistance at low temperatures. A very sensitive low temperature test procedure was established to detect trace quantities of water vapor.

Thirty-three potentially age hardenable silver-palladium-X and silver-platinum-Y ternary alloys were studied in the development of a monolithic contact system. Tests of the physical and mechanical properties after various heat treatments, relative relaxation, and contact resistance measurements were performed.

Monolithic contacts were fabricated using two compositions of silver-palladium-copper alloys and manufactured into "sealed switching module" relays. There was no indication of cold welding under low level conditions, and the contact resistance stability of the sealed module was comparable to gold plated contacts.

INTRODUCTION

The purpose of this program was to study the process, material, and contamination aspects of high reliability relay manufacture and to relate these variables to overall electrical contact performance. This study was built around the "sealed switching module" contact system introduced by Deutsch Relay Division. It is through the utilization of this unique relay design, which eliminates the gross influence of coil contamination, that a program of this nature could be successfully undertaken. It was not the intention of this study to develop new relay designs, but rather to accurately establish the process and material parameters that influence reliable contact performance.

An engineering manufacturing facility, under the control of the project engineer, was utilized to manufacture switching modules of the Super-J configuration illustrated in Figure 1. This process facility was capable of manufacturing a small quantity of Super-J relays from the sub-assembly stages through the final operations under closely controlled conditions. It utilized the latest state-of-the-art cleaning, welding, handling, and control techniques that are currently employed in manufacturing operation.

Some of the critical control aspects, such as level of particulate contamination, influence of leakage and water vapor effects, were evaluated with respect to process controls and the effect on performance. The study of processes and contamination levels and their effect on performance naturally leads to the question of contact materials, since reliable contact performance is not only dependent upon the processes and contamination factors, but also on the intrinsic contact material characteristics.

Due to the nature of the areas to be investigated, two separate, but concurrent and coordinated phases were studied. The process and contamination evaluation phase dealt with the study and development of the correlation among contact performance, contamination levels, and the manufacturing processes for a constant design and materials geometry. This phase used the Super-J relay configuration with standard gold plated contacts (2-4 microns Au-Co electroplate over 99Ag, 1Pd substrate). Relays were manufactured in small groups of 8-10 units in the engineering facility using laminar flow clean benches meeting class 100 conditions of MIL-STD-209. Tests in the low level, intermediate, and power load regions determined the overall process uniformity and established basic contact material limitations.

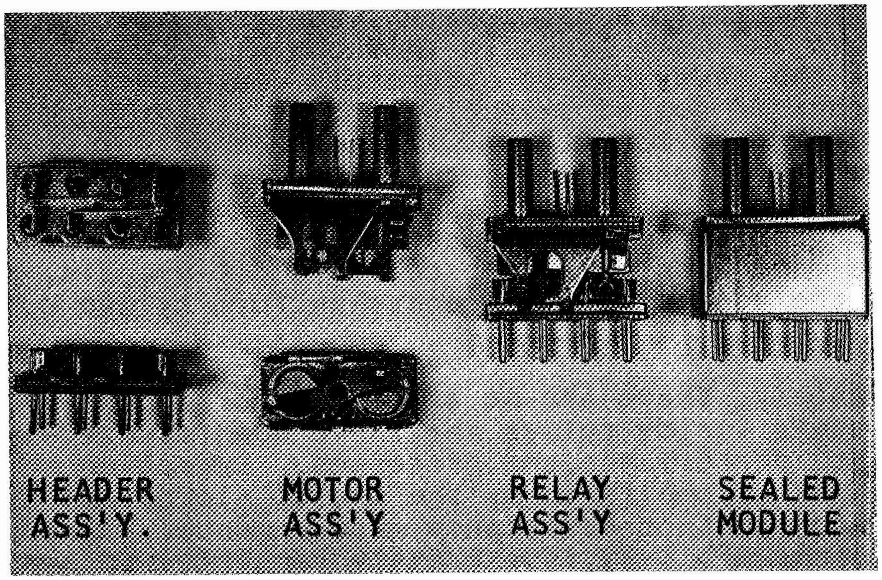


FIGURE 1 SUPER-J Sealed Switching Module Assembly

Running concurrently with the process and contamination evaluation phase of the program was a material development phase. The ultimate objective in the study of contact materials was the development of a monolithic material that would be a combined high temperature spring and contact material which would require neither plating nor cladding and would be capable of switching signals in the low level, intermediate, and power load regions.

Various ternary alloys in the Ag-Pd and Ag-Pt family were screened with respect to fabricability, high temperature performance, contact characteristics and spring characteristics. Techniques were utilized that allowed for the selection of prospective materials without the necessity of fabricating the materials into detailed parts. A group of rhodium plated contacts as well as two groups of silver-palladium-copper alloy contacts were manufactured into Super-J relays and tested, proving the feasibility of both rhodium and the Ag-Pd-Cu monolithic contact materials.

PROCESS AND CONTAMINATION

Overall reliable relay performance is caused by a chain of events; design, materials, processing, controls, contamination, and testing are the main links in this chain. The objectives of this phase of the study was to accurately characterize the contact performance of sealed switching module relays manufactured under closely defined conditions. The effect of various processes on contact performance was carefully determined by the application of contamination and detection techniques and correlated to contact performance tests. Small quantities of Super J relays were manufactured and tested on a daily basis, thereby allowing for the assessment of process uniformity and contamination levels.

Unfortunately, there are no standards for acceptable contamination levels inside relays that have been accurately correlated to both performance and processes. Detection of contact contamination is accomplished by the use of electrical tests that depend upon contact resistance measurements. Although contact resistance (Ref. 1-3) is extremely sensitive to particulate and film types of contamination that are within the "region of influence," it is only capable of characterizing a very small portion of the relay's surfaces. In addition to contact resistance tests, mobile particulate contamination is assessed by direct observation at 10X magnification after the final cleaning operations. This technique is not quantitative, is highly dependent upon the operator, and is limited to particles in the 25-50 micron range.

Contact resistance and visual observation contamination detection techniques are not sensitive to the gaseous forms of contamination, such as water vapor or residual organic films. Water vapor is a very serious problem due to "icing" at low temperatures. This form of contaminant can be found inside sealed relays due to inadequate final vacuum outgassing processes or diffusion through glass-to-metal seals. It was not within the scope of this study to investigate glass-to-metal seal leakage, but rather to characterize the leakage problem by its effect upon performance.

It is important to recognize that contamination and processes are closely related. Relay manufacturing processes are designed to minimize contamination levels inside relays. In some cases, the process variablesare not closely controlled, and it is possible for the process to introduce contamination into the relay rather than remove it. This can occur during cleaning operation when the solvent purity is not controlled, or during welding operation where excessive weld splash or material transfer is present. Vacuum outgassing and backfilling processes can result in the introduction of organic contamination due to untrapped mechanical or diffusion pumps. Residual water vapor levels are determined by the final vacuum outgassing and backfilling processes. It has been the experience of Deutsch Relay Division that the critical operations during the manufacture of high reliability relays are the cleaning, welding, and vacuum outgassing operations.

In some cases, the critical process control parameter is not accurately known or is inadequately controlled. The main reason for this is that there is limited knowledge in the field as to which is the most critical parameter to control and also its influence on product performance. For example, water vapor levels inside sealed relays are generally specified in terms of the dew point of the backfill gas and also the water vapor concentration in the final sealing chambers. Dew point levels below -65°C (Approx. 10 ppm) are commonly specified. Research at Deutsch Relay Division indicates that excessive friction, wear and adhesion (cold welding) occur on relays that are processed under very dry conditions. Water vapor acts like a boundary lubricant and lack of this trace lubricant results in excessive friction and wear problems. This is a process control problem, since too much water vapor will cause low temperature failures, while insufficient quantities will result in cold welding and excessive wear failures.

By the application of advanced contamination detection techniques (Ref. 4-6) recently introduced into the contamination control field, it was possible to characterize the type and level of contamination on relays as a function of various manufacturing processes.

PROCESS EVALUATION

This phase of the study was concerned with accurately characterizing the various processes with respect to uniformity, control, and contamination levels. Figure 2 is a flow chart of the key assembly operations. The engineering Super J line, wherein referred to as the ESJL, and associated equipment is illustrated in Figures 3-5.

The critical assembly operations were mounted in class 100 clean benches as indicated in Figure 2. Operating personnel were trained in the use of the equipment, and all personnel were garmented and capped. Finger cots or plastic gloves were used on all assembly operations performed in the benches.

<u>Particulate Contamination Tests</u>.--The class 100 benches, both the vertical and horizontal flow types, were checked initially for air flow velocity in accordance with FED-STD-209. A Taylor velometer (vane type) was used to check various locations across the face of the HEPA filters. There were no major variations from the requirement of 80-120 feet per minute. No attempt was

made to determine the turbulance in these benches, but rather only to assure that the air flow was representative of class 100 benches.

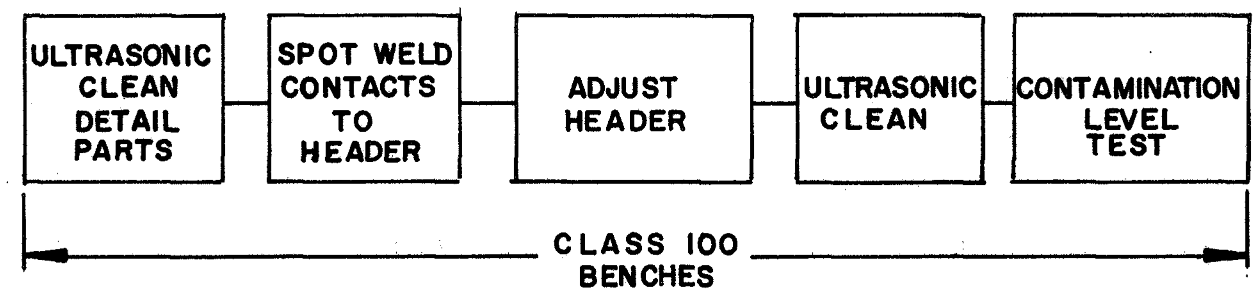
The next series of tests that were conducted were for particulate contamination in the 5 micron range. A Dynac model M-101 particle counter was used. The sampling flow rate was 6-cfh. Two channels were available for sizing particles in the 0.5 to 5.0 micron range and those above 5.0 microns. In the static condition (no worker activity), the benches met the requirements of no particles greater than 5.0 microns and less than 100 particles in the 0.5 to 5.0 micron range. This was achieved only by special attention to cracks and leaks that were initially found in the equipment. It was not possible, of course, to maintain the class 100 conditions during the assembly operations. Any worker activity, particularly during resistance welding operations, would generate an excessive number of particles above the limits. No attempt was made to count these particles or characterize the work condition using the Dynac counter, since it was recognized that these types of assembly operations generate particles. It was felt that this series of tests indicated that there was a minimal amount of airborne contamination in the assembly area associated with the environment. The increase in particulate contamination was associated with worker activity and the assembly operations.

Aerosol monitoring techniques were used to characterize particles above 25 microns. This technique, outline in ASTM F25-66T, uses a 47 mm membrane with a pore size of 1.0 micron. By drawing an air sample through the membrane, typically ten cubic feet, the particles collected on the membrane can be visually inspected and characterized. A monocular microscope (magnifications of 40X and 100X), mounted in a class 100 bench, was used to observe the types of particles.

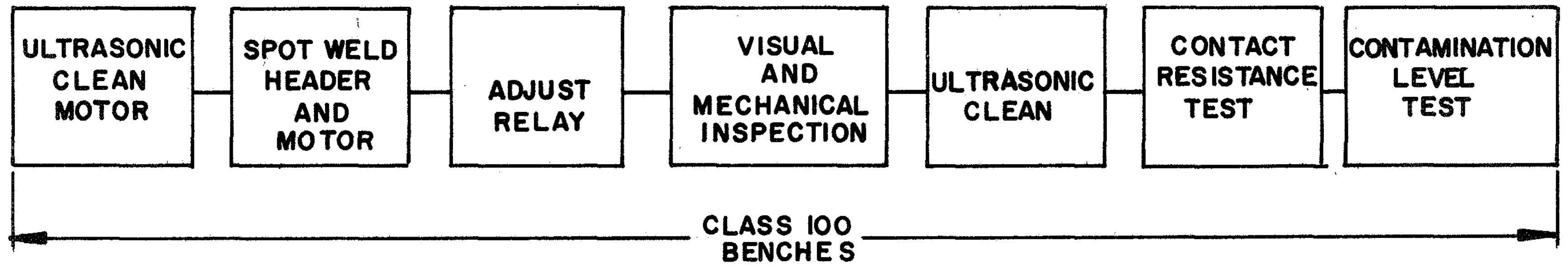
In general, the major contaminants observed were fibers associated with the garments and plastic material associated with the gloves and finger cots. Although other types of particles were observed, these species were the most common. It was not the purpose of this evaluation to perform statistical particle counting tests, but rather to characterize the species of particles for latter correlation to those associated with relays after testing. It is felt that the particle level could be lowered by closer controls on personnel and assembly operations, but the subsequent test results did not warrant these extremes.

Inspection of the sub-assemblies and final module assembly after cleaning was performed using a 10X-30X stereomicroscope. This was performed on 100% of the assemblies. Typically, weld flash associated with the header assembly and plastic materials associated with the finger cots/gloves were found at this stage of evaluation. These levels were a function of operator training and highly dependent upon the number of times a module was handled after cleaning.

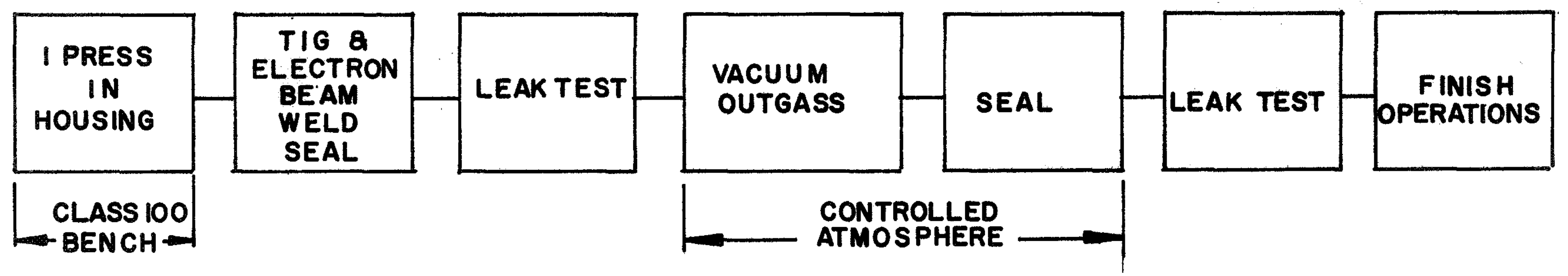
HEADER ASSEMBLY OPERATIONS



MOTOR-HEADER ASSEMBLY OPERAIONS



FINAL OPERATIONS



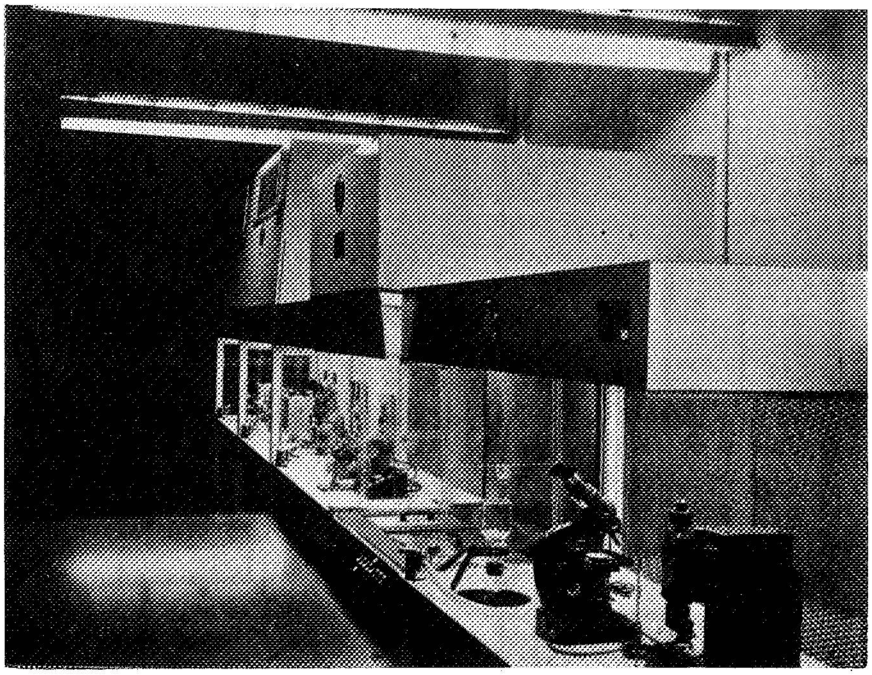


FIGURE 3 Engineering SUPER-J Assembly Facility in Class 100 Benches

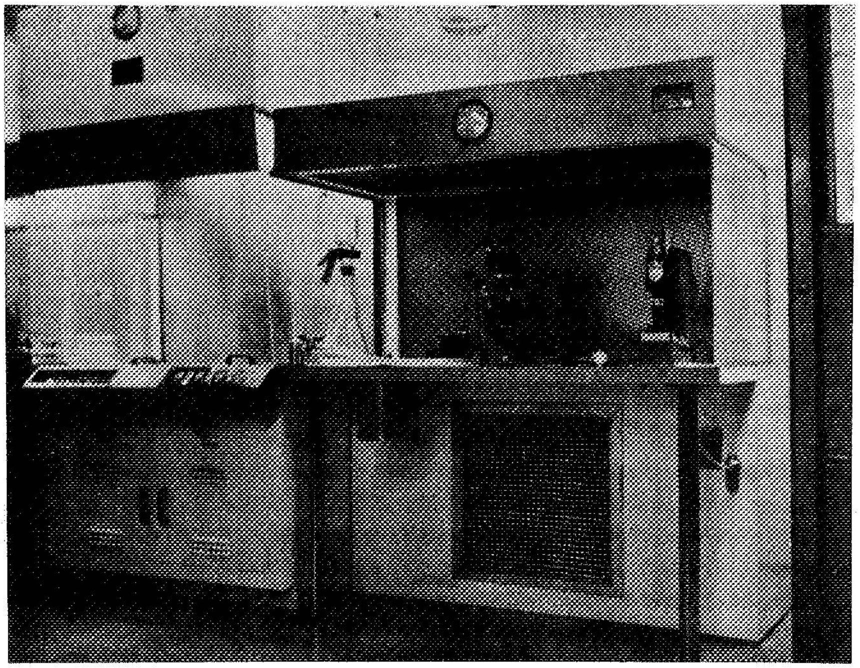


FIGURE 4 Ultrasonic 6-Step Cleaning Station and Inspection Bench (Class 100)

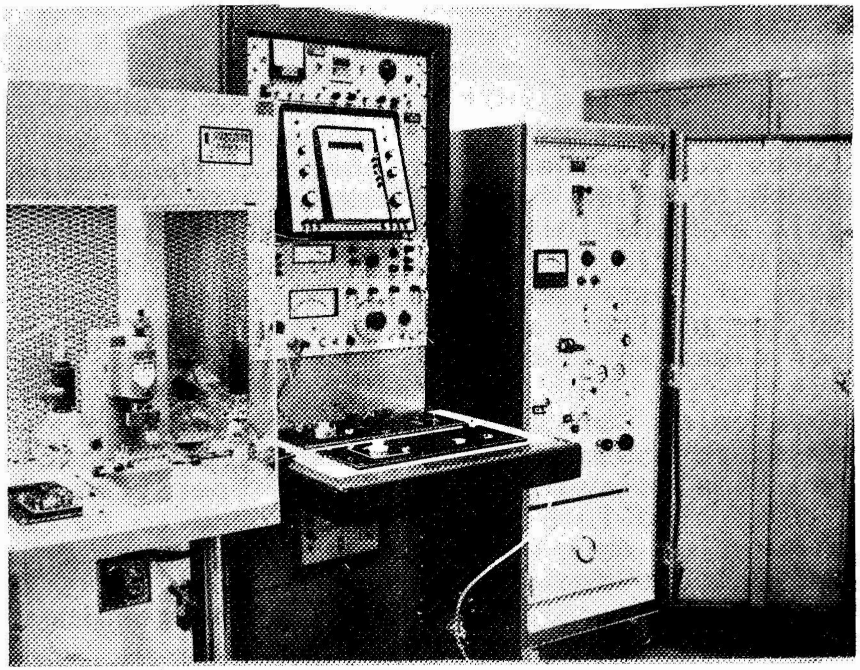


FIGURE 5 Contact Resistance Test Station and Solvent Purity Meter

In subsequent comparisons, little data was found to draw a direct comparison between the particles found during the assembly operations prior to sealing and those inside relays.

Ultrasonic Cleaner Evaluation.--Since the cleaning operation is felt to be one of the most critical during the assembly of the modules, a variety of tests were performed on this process. Briefly, the cleaning system is a six step, two solvent, ultrasonically agitated, (40 KHz), recirculating and redistilling cleaner mounted in a class 100, vertical flow clean bench. This system uses Freon TWD-602, a water-surfactant-Freon TF emulsion solvent, coupled with a Freon TF-Menthonal azeotrope solvent in a vapor degreaser configuration. Both solvents were continuously recirculated through filters in the 5-25 micron range. A hand spray lance with a 5 micron membrane filter was used to spray rinse the parts prior to their final vapor rinse. The selection of these solvents was based on prior experiments during the development of the Super-J relay. They are considered to be highly effective in removing the bulk of handling contaminants commonly encountered in these assembly operations. Care must be exercised to assure that the surfactants are completely removed during the rinsing steps in the Freon TF-Menthonal azeotrope.

The cavitation intensity in both the ultrasonic tanks was measured using a Macrosonics Cavitation Meter, Model MCB. This instrument, according to published literature, closely correlates to other forms of cavitation intensity measurements such as chlorine release and lead/aluminum erosion tests. This direct reading instrument detected initially a loose transducer element on one of the cleaners and was used to monitor and optimize the cleaning fixtures during the design phases. The readings were not stable enough to allow for the routine use of this instrument on a daily basis and the initial evaluation of the process did not indicate major variation in the cleaning equipment to justify this degree of instrumentation. This type of equipment is ideally suited for periodic monitoring of similar cleaners and optimization of cleaning fixtures.

A Jet Electronics Corp. Solvent Purity Meter, Model SPM, was used to evaluate and monitor the Freon TF-Menthanol solvent used during the final cleaning operation. Operation of the instrument, illustrated in Figure 5, was found to be fairly simple and calibration data was reproducible to better than 5%. Measurements of soluble residual contamination levels in the cleaner were found to be relatively fast since readings are made as soon as a sample is introduced into the device.

Calibration curves were made in the range between 1 and 100 ppm using Freon PCA and DC704 diffusion pump oil as a standard contaminant. The ultimate sensistivity was found to be below 1 ppm. This instrument was used on a daily basis to monitor the purity of the solvent in the final ultrasonic tank as well as the purity of the spray lance solvent. Since the cleaner continuously distills the solvent, it was possible to maintain the spray lance purity below 3 ppm. Typical readings ranged between less than 0.25 ppm to 2.2 ppm for the spray lance and 0.5 ppm to 14 ppm for the ultrasonic tank solvent.

In addition to monitoring the ultrasonic cleaner, the solvent purity meter was used to evaluate the change in removable contamination from assemblies before and after the cleaning process. The assemblies were ultrasonically agitated in a virgin solvent before cleaning and a reading was obtained on the solvent. The same technique was used after the parts had been cleaned in the standard six step cleaning process. Typically, the readings before cleaning indicated a level between 5 and 10 ppm per unit. After cleaning, the level was not detectable, (i.e. below 0.25 ppm). This does not imply that the parts were completely clean, but rather the fact that no additional contamination could be removed by the process. Additional information concerning the application and principle of operation of this equipment can be found in the references (Ref. 6 & 7).

In order to determine and evaluate the species of particles associated with the cleaning operation, hydrosol techniques were used. A membrane filter, pore size of 1.0 micron, was used to filter 100 ml samples of the solvent. The particles associated with the system were readily visible at magnification of 40X and 100X. Numerous tests were performed to categorize these particles. In general, both fibers greater than 100 microns and particles in the 5 to 50 micron range were found. Some of these were associated with the recirculation system on the ultrasonic cleaner, while others were typical of handling byproducts such as skin, plastics, and garment fibers. A nominal attempt was made to reduce the level in the cleaners; however, they were not of a magnitude to be considered gross since gravimetric measurements of the non-volatile residue did not exceed 30% of the soluble residue as measured on the solvent purity meter. As a control technique, the solvent purity meter was used exclusively after this initial evaluation.

Resistance Welding Evaluation.--Evaluation and optimization of the weld schedules using the techniques outlined in NASA SP-5011, "Welding for Electronic Assemblies," were performed on critical welds of the fixed contacts to the header assembly. Since this was a source of weld flash, an investigation was made to determine the optimum weld schedule with respect to strength and minimal weld flash.

The projection welding operation utilized Unitec DC capacitor discharge welders. The fixed contacts were gold plated bimetals of silver and nickel. The weld was made between the nickel backing and a 52 alloy nickel-iron terminal pin. Weld strength tests were routinely made during the manufacturing phase of the study. It was determined that, as a result of the material combinations (nickel and 52 alloy nickel-iron), a weld schedule could not be developed which would yield satisfactory weld strength without the necessity of a weld flash removal operation. This process was critical from the standpoint of loose metallic particulate contamination since it involved a manual "picking" operation.

This problem of weld flash and associated particulate contamination can be resolved by the use of a different contact backing alloy that more closely matches the electrical resistivity of the terminal pin material. The electrical resistivity of the 52 alloy terminal pin is 43 micro-ohm centimeters, while the nickel contact material backing is only 9.5 micro-ohm centimeters. By using a copper-nickel alloy with a resistivity of 37 micro-ohm centimeters, the weld flash problem can be eliminated without sacrificing the strength. Metallographic comparisons of the fusion zones of these two materials confirmed this finding. Unfortunately, this contact material was not available for the program, and the nickel backed contact alloy was used for the manufacture of the test relays. This is an area for additional optimization at some later date.

Vacuum Outgassing Evaluation.--The vacuum outgassing process was initially catagorized, from past experience, as being one of the most critical. The vacuum system was completely trapped. The oil-diffusion pump was trapped with an ambient baffle and a liquid nitrogen trap. The mechanical pumps were trapped with zeolite molecular sieves. The entire system was automatic and interlocked. The vacuum oven was of the double door construction which allowed for loading of the relays in air and unloading the units in a controlled atmosphere recirculating type dry box. Inside the dry box, a DC resistance welder was installed for final sealing the 1-mm vacuum outgassing orifice with a ball. The atmosphere of the dry box was recirculated through an oxygen furnace to remove traces of O_2 and a "dryer" of the molecular sieve type to reduce the water vapor level to less than 10 ppm. The dry box was filled with the backfill gas: 9-11% helium, balance nitrogen. This mixture was monitored with a gas chromatographic system. Water vapor was measured with a panametrics type moisture monitor probe capable of resolving less than 10 ppm.

The initial vacuum outgassing cycle was developed by similarity to the existing techniques. It was a 200°C, 16 hour, less than $5(10^{-5})$ torr, less than 20 ppm H_2O backfill atmosphere ("dry"). During the early phase of the study, a high percentage, greater than 50%, of the relays exhibited low level cold weld failures after 20,000 to 30,000 cycles. The results were inconsistent; however, it was noted that there appeared to be some correlation between the amount of water vapor inside the contact module and the cold welding. Using this hypothesis, it was decided to optimize the vacuum outgassing cycle so that a sufficient level of residual water vapor was left inside the contact module to act as a boundary lubricant and thereby minimize the sticking problem without creating low temperature "icing" problems at -65°C. Using this approach, a series of experiments were performed in which the moisture level in the dry box was increased up to 2,000 ppm and the time temperature and ultimate pressure were varied as shown in Table I.

It was concluded from these series of experiments that the 16 hour, 200°C, less than $5(10^{-5})$ torr cycle coupled with a "dry" backfill atmosphere was causing excessive cold welding which could be successfully minimized by reducing the time and temperature of the vacuum outgassing process. An optimized process that was used throughout the entire study was a compromise between low temperature performance and cold welding. It should be borne in mind that the cold welding phenomenon is a material limitation which is minimized, but not eliminated, by leaving a higher residual water vapor level inside the contact modules as a result of the vacuum outgassing processes. The finalized cycle was: 175°C, 1 1/2-hours, less than 10^{-2} torr (trapped mechanical pump) with a "dry" backfill and dry box atmosphere of less than 20 ppm water vapor.

As the preliminary results indicated and the results reported in the next section confirm, this was a marginal condition at best, and the final solution to the cold welding phenomenon on contacts operated in a "dry" atmosphere involves a contact material change.

TABLE I

COLD WELDING, LOW TEMPERATURE PERFORMANCE, AND VACUUM OUTGASSING PARAMETER EXPERIMENT SUMMARY

Vacuum Outgassing Parameters			Dry Box	Test Results	
Temperature (°C)	Time (Hrs)	Pressure (Torr)	Moisture Level (ppm)	Cold Welding (Failure/Qty)	-65°C CR
200	16	(10^{-5})*	20*	12/17	Passed
200	16	(10^{-5})*	2,000	None	100%Failure
200	16	(10^{-5})*	300	4/6	Passed
200	4	(10^{-5})*	20*	1/3	Passed
170	3	(10^{-5})*	20*	1/3	Passed
175	2	(10^{-5})*	20*	1/7	Passed
175	2	(10^{-5})*	600	0/9	Passed
175	1	(10^{-5})*	20	0/7	Passed
175	1	(10^{-2})*	20*	0/9	Passed

*Upper limit, less than specified value; CR=Contact Resistance

Contact Resistance Tests.--Contact resistance is considered to be an indicator of the surface condition of electrical contacts. It is quite sensitive to various forms of contamination. The contact resistance distributions of various lots are excellent indicators of process uniformity. Four different techniques of measuring contact resistance were investigated in this phase of the study.

The classical contact resistance technique, as defined by military and other specifications, utilizes the four terminal voltmeter-ammeter method which minimizes the error associated with leads and sockets. Open circuit voltages up to 6 volts are used with currents ranging between 0.1 and 2.0 amperes. A comparison was made between static readings using a 10 milliampere, 50 millivolt DC circuit and a 0.1 and 2.0 ampere, 6 volt DC circuit. No significant defference in measurements could be found on resistances below 100 milliohms. At higher contact resistance, the resistance was so unstable that it was not possible to obtain accurate correlation. It was concluded that if the criterion for acceptance was below 50 milliohms, the measurement parameters were not critical providing the contacts did not make or break the current.

Due to contamination phenomenon, relays can exhibit low and stable resistances for the first three to five operations on the same contact. Then there is a gradual increase in the resistance which will generally appear within thirty operations if the contact is unstable. This variation in contact resistance is readily observable on an oscillographic recorder. Typical recorder traces using a 100 milliampere, 6-volt contact load are shown in Figures 6 and 7. Almost all of these variations would not be detected using the standard three reading method described above. This recorder technique was used as a control method for the final cleaning operations of the contact module. The criteria were a maximum of 30 milliohms and an allowable variation of 5 milliohms in thirty operations. This technique has been found to be simple, fast, accurate, and a more definitive measurement of contact resistance.

Until recently, it was not possible to measure directly the "true" contact resistance of a sealed relay. The previously described methods measure the contact resistance from terminal pin to terminal pin. The ratio of the externally measured contact resistance to the "true" contact resistance is between three and ten depending upon the materials and design. This has a considerable masking effect when one examines the condition of the contact interface by measuring the overall resistance. New techniques which depend upon the non-linear characteristics of the constriction resistance have been reported by Russakoff and Snowball(Ref. 8) and Whitley (Ref. 9). It was felt that these techniques were directly applicable to relays since the "true" contact resistance can be measured directly and errors due to sockets and the masking effect due to the loop resistance are eliminated.

A Burndy model 1.2 contact resistance meter was used to evaluate the application of this technique to the Super-J contact modules. Since this is a laboratory instrument, and measurements of changes of 5 to 10 microvolts are made, it was not possible to perform 100% testing on all units as a control technique. The instrument was calibrated using a gold plated silver alloy cross-rod pair. The"true" contact resistance readings ranged between 0.7 and 5.0 milliohms with an average of 1.1 milliohms. Table II is a comparison between the overall contact resistance and the "true" contact resistance on representative gold plated silver alloy Super-J contact modules. Due to thermal electromotive forces, it was found not to be practical tomeasure the normally open contacts since the time necessary to stabilize the instrument was excessive. It was concluded that this particular instrument was not suited for process control applications because of the complexity of the measurement which was also time consuming. That is not to say that the

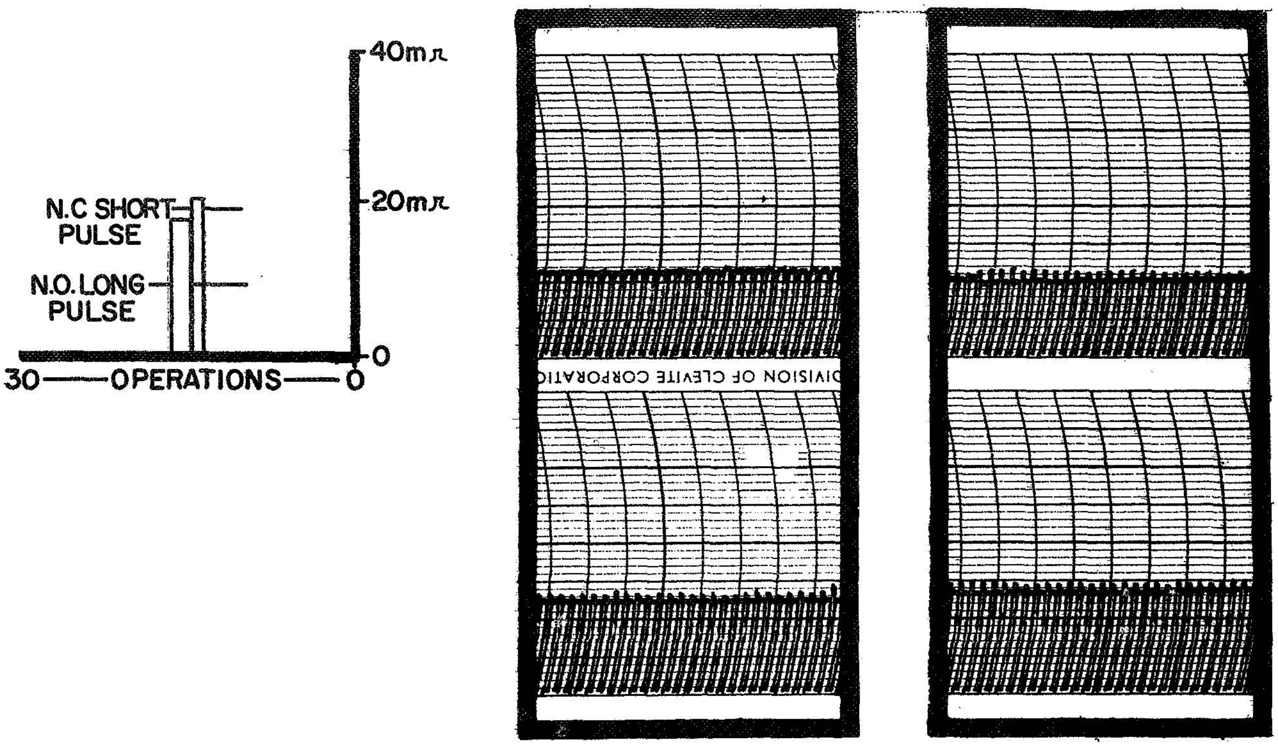


FIGURE 6 Contact Resistance 0.1 Amp, 6 Volts, DC
30 Operations. Examples of Stable Contact Resistance

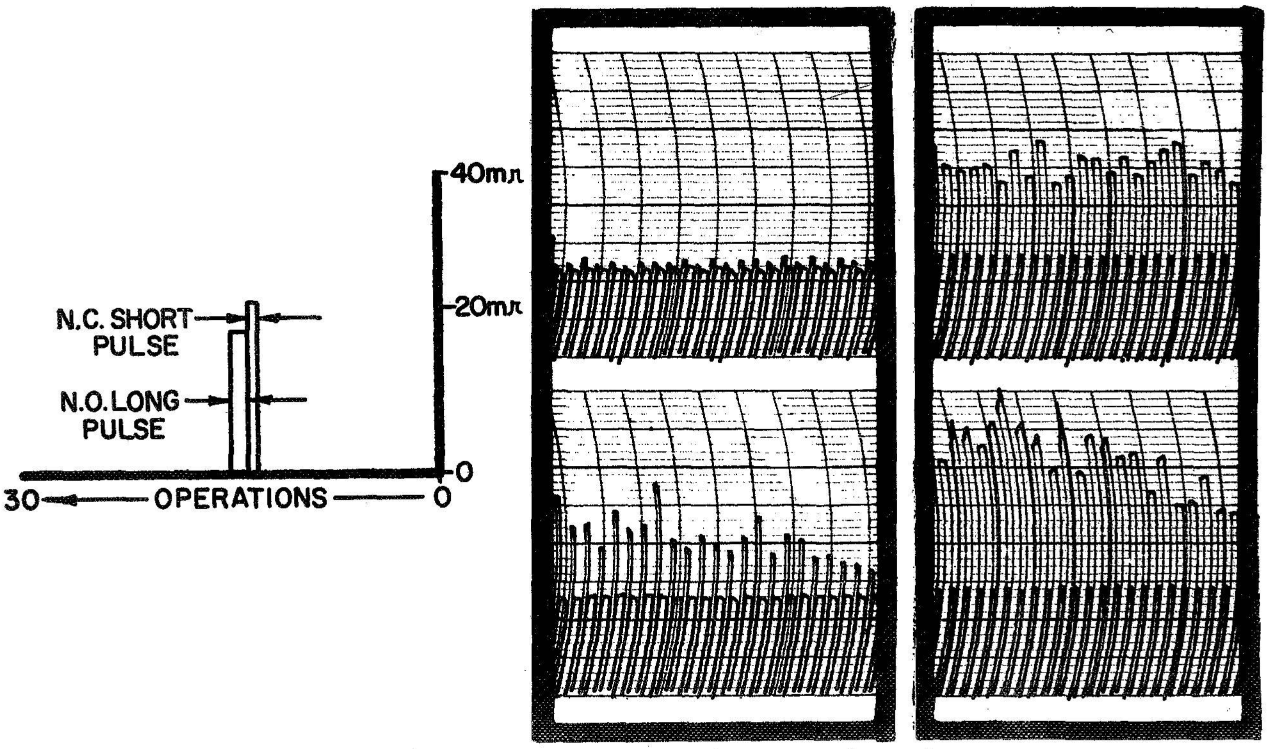


FIGURE 7 Contact Resistance 0.1 Amp, 6 Volts, DC
30 Operations. Examples of Erratic Contact Resistance

principle was not valid for process control applications, only that this particular device was designed more for laboratory measurements.

TABLE II

REPRESENTATIVE SUPER J OVERALL CONTACT RESISTANCE

COMPARED WITH "TRUE" CONTACT RESISTANCE

Contact Number	Reading	Overall Resistance (Milliohms)	"True" Resistance (Milliohms)
NC4	1	12.3	0.7
	2	12.3	0.7
NC8	1	13.8	1.0
	2	13.7	1.0
NC4	1	12.2	0.5
	2	13.5	1.5
NC8	1	12.8	0.8
	2	12.9	0.9
NC4	1	13.2	1.2
	2	13.1	1.1
NC8	1	14.1	1.2
	2	13.7	1.0
NC4	1	12.9	0.7
	2	13.8	2.0
NC8	1	13.8	1.5
	2	13.8	1.5

The remaining contact resistance measuring technique that has direct process evaluation applications as well as contact material evaluation applications, utilized the ASTM micro contact tester (Ref. 10 & 11). This instrument uses 0.015" diameter, crossed-rod geometry wires to measure directly the contact resistance. By using high purity, etched gold wires, it is possible to evaluate the influence of various cleaning solvents by comparing the measurement to a gold standard cleaned by chemical techniques. This procedure was evaluated initially with respect to the ultrasonic cleaning solvents and the effect of storage on contact resistance. Due to the range of data below 1.0 gram, only those values above 1.0 gram were considered significant. Based on these tests, it was determined that the cleaning system did not leave a residue that directly affected the contact resistance. This equipment is quite delicate and was used only in these initial studies and the contact material phase to demonstrate the ability of the cleaning system to yield stable contact resistance when compared to theoretical values.

Leakage Tests.--The overall performance of the Super J contact module was highly dependent upon the degree of hermeticity obtained. As a result, four measurements of seal integrity were made during the study on all relays.

Immediately after the electron beam weld sealing of the header to the housing and the TIG weld sealing of the seal plate to the motor assembly, a gross leak test was made on all units. The test was performed by pressurizing the inside of the module with 45 psig of nitrogen and submerging the entire module in Freon. Any bubbles emitting from the module were indicators of excessive leakage. In general, the major areas of leakage found at this point were associated with the motor assembly and the brazing operation used to secure the cores to the seal plate.

All units that passed the gross leak test were subjected to a fine leak test by evacuating the inside of the relays, through the outgassing orifice, on a VEECO MS-12-Ab helium type mass spectrometer leak detector, the sensitivity of which was less than $5(10^{-11})$ atm cc/sec of helium. By spraying helium from a fine probe, it was possible to pin-point leak locations if they were greater than 10^{-9} atm cc/sec of helium. This information was accumulated for all relays.

Following the vacuum outgassing operation, when the contact module was completely sealed (and backfilled with a 10% tracer of helium), an additional set of readings were made on the module by using the "bell-jar" technique. The final readings were made following the life tests using the same technique as above. All this information was used to correlate performance, atmosphere and leakage on the Super J test relays.

Manufacture of Test Relays

This phase of the study was concerned with establishing the overall process uniformity and relating process and contamination variables to contact performance. Only minor process variations were permitted. The contact material was held constant; i.e. gold plated silver alloy contacts.

The contact adjustment parameters were frozen and no variation was made from the limits reported in Table III.

TABLE III

CONTACT ADJUSTMENT PARAMETERS

Normally closed contact force	9-13 grams
Normally open contact force	17-23 grams
Contact gap	0.010-0.012 inch
Return spring force	7-10 grams

Since these relays are force adjusted, the operate and release voltage is not an adjusting parameter as is the case on conventional relays.

A total of five lots (14, 16, 18, 20 & 22) were manufactured in small groups of 7 to 10 relays each. These units were manufactured on a daily basis and tested for contact performance within two days. In this way, it was possible to correlate process discrepancies with contact performance on a short term basis. The overall manufacturing yield was 78%. This low yield was completely associated with leakage of the module.

TABLE IV

SUMMARY OF LOT AND GROUP SIZES OF SUPER J CONTACT MODULES MANUFACTURED

Lot	Groups	Qty. Loaded	Qty. Tested	Yield
14	3	21	21	--
16	12	84	76	91%
18	10	73	46	63%
20	8	56	39	70%
22	3	30	22	74%
TOTAL	36	264	204	78%

Although these yields appear low, it must be borne in mind that the criterion for leakage was less than $2(10^{-9})$ atm cc/sec and units were not tested that exhibited leaks greater than 10^{-6} atm cc/sec. These units that had or developed leaks during the life tests supplied significant information concerning the effect of hermeticity on contact performance. Table V is a representative summary of the hermeticity of the contact modules at various stages of the study.

TABLE V

HERMETICITY OF CONTACT MODULES DURING VARIOUS PHASES OF THE STUDY

	Leakage Class (Atm cc/sec of Helium)					
						Gross
	$2(10)^{-9}$	10^{-8}	10^{-7}	10^{-6}	10^{-5}	10^{-5}
Before Vacuum Bake	29%	6%	2%	2%	1%	60%
Prior to Tests	54%	5%	14%	10%	11%	6%
After Life Tests	61%	27%	4%	6%	2%	---

The high incidence of gross leakage before the vacuum bake and the radical change in yield is associated with the hermeticity of the motor assembly. The apparent improvement in the yield is associated with the sealant used as a moisture barrier between the coils and seal plate prior to vacuum baking. This silicone resin acted as a sealant of a temporary nature; however, no sealant was used on the header.

A detailed analysis of the location and cause of the leakage problem was performed. The results indicated that over 90% of the failures were due to a marginal or defective braze seal between the core and seal plate of the relays. This did not show up during the initial hermetic tests on the motor assemblies after brazing. However, it became pronounced when the units were TIG welded (most likely due to the thermal stresses) and also during the final operations where the backstrap was crimped to the cores (most likely due to the mechanical stresses on the braze joints). The braze sealing operation was performed in a hydrogen atmosphere using a eutectic gold germanium alloy. This material has a very low ductility (2-3%) and the eutectic alloy is apparently not suitable for brazing large gaps. Shrinkage cavities were encountered as evidenced in metallographic cross-sections.

As a result of these findings, Lot 18 utilized a two step, AgCuSn braze process designed to minimize this problem. There was a marked improvement in leakage results, but the motor adjustment was affected and loss was encountered due to the mechanical and magnetic problems associated with this process. Lots 20 and 22 used the gold-germanium braze alloy with reduced braze gaps in the motor assembly and acceptable results were obtained with respect to strength and hermeticity.

Contact Performance Tests

A worst-case test program was designed to stress the effects of materials and contamination on contact performance. Particular attention was given to the low temperature test procedure since the effect of water vapor on contact performance was considered as a major factor on these relays.

Test Procedures.--All units were measured for their initial and final electrical characteristics on automatic test equipment. Measurements of coil resistance, operate-release voltage and time, contact bounce and contact resistance at 100 milliamperes, 6 volts (eleven readings per contact) were performed. This data was punched on IBM cards and run through an IBM 360/20 system for collation and print-out. The data was presented in such a form that the initial and final readings on the same relay were below one another. These tests were all performed at room temperature (20-32°C).

The life tests were divided into three levels: low level, intermediate, and power loads. The specific procedures are outlined below.

Low level life tests were conducted using 300 microampere, 30 millivolt, 1 KHz, signals with a detection criterion of 10 ohms contact resistance and/or a contact weld in excess of 50 milliseconds. A cycling rate of 240 operations per minute was used. It was possible on this equipment to determine the difference between misses that were due to contact resistance and those associated with welding. The test sequence was:

1. Contact Resistance at 125°C, 3 Rdgs./cont.
2. 50,000 Operations at 125°C
3. Contact Resistance at 125°C, 3 Rdgs./cont.
4. Thermal Shock De-energized to -65°C, soak 1/2 Hour,Energize 1/2 Hr.,Measure Contact Resistance, 3 Rdgs./cont.
5. 50,000 Operations at -65°C
6. Contact Resistance at -65°C, 3 Rdgs./Cont.
7. Contact Resistance at 25°C, 3 Rdgs./Cont.

This low level life procedure was extremely useful in correlating the low temperature contact performance with moisture. Step 4 is quite critical since it is designed to subject the contact module to the largest temperature gradients.

The intermediate load life tests were run using a 100 milliampere, resistive, 28 volt DC contact load. In the majority of cases, an oscillographic recorder was used to measure the contact resistance during each operation. The total operations were 100,000 cycles at 125°C with a cycling rate of 90 operations per minute. This test is quite sensitive to organic contamination and can cause the contact resistance to increase to the order of 1 to 10 ohms due to an "activation" phenomenon.

Power load life tests were conducted at 125°C using a 2-

ampere, resistive, 28 volt DC and a 60 operation per minute cycling rate. The failure criterion was contact resistance in excess of 3 ohms and/or welds greater than 50 milliseconds. The failures were catagorized according to parametric types where only a miss would be registered and catastrophic types where a visual indication of a contact failure was observed.

There was no variation in these procedures during both phases of the study. All data is directly comparable.

Test Results.-- Table VI is a summary of the overall contact performance of the 188 relays tested

TABLE VI

SUMMARY OF OVERALL CONTACT PERFORMANCE OF LOTS 14, 16, 18, 20 & 22

	36 Groups, 188 Relays
LOW LEVEL LIFE TEST	
Miss Failures in 10^5 Operations	25/69
Miss Failures at 125°C	16/25
Miss Failures at -65°C	13/25
CR 30 Milliohms at 125/25°C	6/69
CR 30 Milliohms at -65°C	22/69
INTERMEDIATE LOAD LIFE (100 ma)	
CR 100 Milliohms	1/58
Welds	4/58
POWER LOAD LIFE (2 Amperes)	
Catastrophic Failure Mode	8/61
Parametric Failure Mode	25/61

Notation: Failure/sample size; CR Contact Resistance

The lot uniformity is tabulated in Table VII.

Analysis of the electrical characteristics measured before and after the life tests indicated that they were remarkably stable. The most significant parameter was the comparison of the contact resistance measurements. Of the 17,688 readings, only five contacts exceeded 30 milliohms. They ranged between 35 and 66 milliohms and were associated with relays that had been subjected to the intermediate load life tests. There was no significant shift in the contact resistance distribution as a result of the 100,000 operation life tests. The average contact resistance was 23 milliohms with a range of 18 to 28 milliohms, excluding the five contacts above 30 milliohms. In general, there was no shift in the electrical parameters that correlated to the life test failures.

The low level life test results were characterized by two types of failure modes. The first occurred during the 50,000 operations at 125°C and was found to be caused by cold welding of the contacts. Typically, 20,000 to 30,000 operations were required before this failure mode was evident. This was due to the wear of the gold plate and the subsequent exposure of the silver substrate which was the material that was prone to cold weld. This mode would occur only on relays that exhibited no evidence of temperature dependent failures. The second failure mode occurred at low temperature and was associated with a module's atmosphere (high concentrations of water vapor). It is estimated that these failure modes were approximately equally divided and represented two fundamental mechanisms.

TABLE VII

LOT TO LOT CONTACT PERFORMANCE UNIFORMITY

	14	16	18	20	22
LOW LEVEL LIFE TEST					
Miss Failures in 10^5 Oper.	4/6	8/25	3/17	8/14	2/7
Miss Failures at 125°C	4/4	4/8	1/3	5/8	2/2
Miss Failures at -65°C	1/4	5/8	2/3	5/8	0/2
CR 30 Milliohms at 125/25°C	1/6	1/25	3/25	4/14	0/7
CR 30 Milliohms at -65°C	1/6	9/25	6/25	5/14	1/7
INTERMEDIATE LOAD LIFE (100 ma)					
CR 100 Milliohms	0/6	0/23	1/14	0/8	0/7
Welds	1/6	1/23	1/14	0/8	1/7
POWER LOAD LIFE (2 Amperes)					
Catastrophic Failure Mode	0/4	4/22	4/14	13/15	4/8
Parametric Failure Mode	0/4	0/22	1/14	3/15	3/8

Notation: Failure/Sample Size; CR Contact Resistance

The intermediate load life tests (100 milliampere) were quite consistent. Only one unit exceeded 100 milliohms. This confirms the hypothesis that the organic contamination levels in the contact modules are quite low. Normally open contact welds were encountered and this correlates with the failure mode found during low level life tests. This is not a "cold weld" since a slight amount of arcing occurs with this contact load; however, the fact that the welds did occur on four of the 58 units tested indicates the marginality of the contact material system.

During the power life tests at 125°C, the predominate failure mode was welding of the normally open contacts. Eight failures were visually confirmed and the majority of the parametric failures are suspected to be short duration, weak welds on the normally open contact material.

In general, this test program indicated two basic types of failure modes: welding of the contact material and low temperature contact resistance failures. The exact correlation and failure mechanism was studied in the following section.

Relay Analysis and Correlation

In analyzing the data and failures, some interesting abnormalities were uncovered. As previously indicated, there appeared to be a correlation between the cold welding, atmosphere and leakage parameters in general. This was independent of contact loads but was most pronounced during the low level life tests.

Low Temperature Analysis.--Table VIII is a summary of four representative failures that exhibit two different types of abnormalities.

TABLE VIII

TYPICAL LEAKAGE, ATMOSPHERE, AND LOW TEMPERATURE CONTACT FAILURES

Unit	Initial Leak Rate	Leak Rate After Test	Helium Conc.	-65°C CR	25°C CR
399	$1(10^{-6})$	$3(10^{-8})$	1.6%	Open	23
420	NDL	NDL	1.0%	Open	19
439	NDL	$3(10^{-9})$	8.5%	Open	20
459	NDL	NDL	8.2%	Open	19

Notation: NDL Not Detectable, less than $2(10^{-9})$; CR Contact Resistance, milliohms.

Relays 399 and 420 are examples of units that have had a complete exchange of the atmosphere due to leakage. Relay 420 is an example of a relay passing all the leak tests because it contained no trace of helium. This leakage was associated with the motor assembly as previously reported. Relays 439 and 459 are examples of relays with apparently good atmospheres, no leakage, and yet they failed the low temperature tests. It was suspected that this type of failure was associated with the vacuum outgassing process. In order to minimize the cold welding problems, as previously discussed, the vacuum outgassing cycle was a compromise between high levels of residual water vapor and a completely "dry" atmosphere. It is possible for the residual water vapor to vary inside the modules depending upon the ambient relative humidity that they are exposed to prior to the vacuum bake. A residual gas analysis was performed on two additional units that exhibited the same failure mode. The results are tabulated in Table IX.

TABLE IX

RESIDUAL GAS ANALYSIS ON LOW TEMPERATURE FAILURES

	Concentration %Vol/Vol.	
Constituent	504	514
Nitrogen	Bal.	Bal.
Helium	8.4	8.5
Oxygen	ND .001	ND .001
Argon	.011	.012
Carbon Dioxide	0.041	0.052
Hydrogen	1.19	0.58
Organics	ND .002	ND .002
Total Gas, cc	1.03	1.01

Notation: ND None Detected, less than

These results indicate no major discrepancies in the atmosphere; however, these units failed repeatedly the -65°C low temperature tests. It is hypothesized that this mechanism is due to the marginal vacuum outgassing time and temperature which can result in a higher than norm level of residual water vapor. Unfortunately, the water vapor, estimated to be greater than 1,000 ppm, is not detectable by mass spectrometer techniques.

It is felt that these two process related mechanisms completely describe the low temperature failure modes. The experiments performed during the process evaluation indicate that the threshold for water vapor related contact failures is of the order of 500-1,000 ppm in the backfill gases.

Cold Welding.--The test data indicated that the incidence of contact welding was never associated with relays that exhibited low temperature failures. This was found to be related again to the atmosphere. Figures 8 and 9 are photomicrographs of typical contact surfaces that have been subjected to 100,000 cycles of low level loads. There is no electrical erosion occurring under these load conditions; this is a mechanical phenomenon.

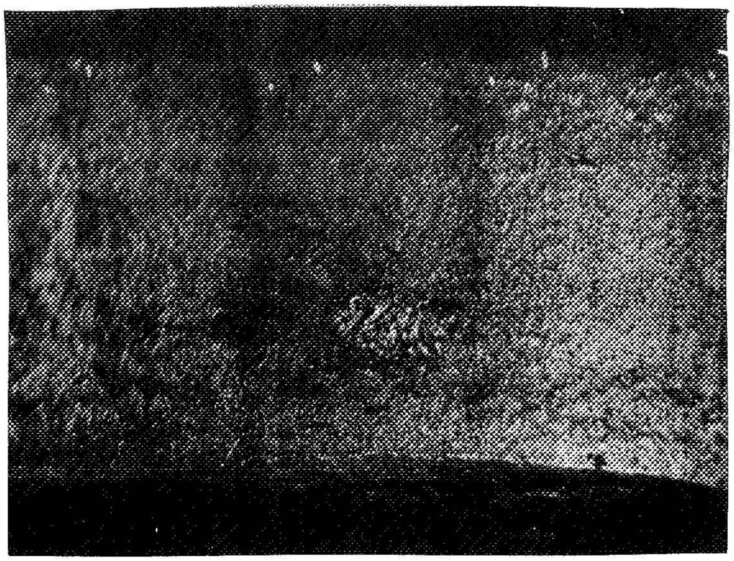


FIGURE 8 150X, Typical Contact Wear Scar On Relay Operated In High Levels Of Water Vapor (Greater Than 1,000 ppm) During Low Level Tests, 100,000 Operations.

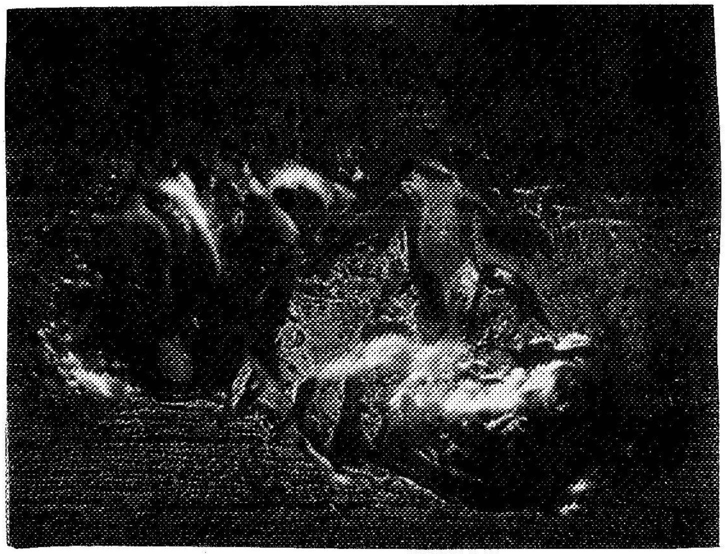


FIGURE 9 150X, Typical Wear Scar On Relay Operated In "Dry" Atmosphere (Less Than 100 ppm). Silver Substrate is Exposed. After Low Level Life Test For 100,000 Operations.

Figure 8 is a contact surface that successfully completed the low level life without failure but indicated low temperature contact resistance failures. There is little evidence of contact wear and no exposure of the soft silver alloy substrate material.

Figure 9 is an example of a contact surface that failed the low level life tests due to cold welding of the normally open contacts. This relay successfully passed the low temperature tests, indicating that the atmosphere was relatively "dry". It was possible to catagorize the atmosphere by the type of contact wear that was observed after the life tests. In the case of a "dry" atmosphere, the contacts were always catagorized by excessive wear through the gold plate and exposure of the silver alloy substrate material. Welding does not occur on the gold plate, but rather on the silver alloy due to its lower hardness (greater plastic deformation) and higher purity when compared to the electrodeposited gold plate.

Contrary to what many specifications today indicate, it is not possible to operate these types of relays in a "dry" atmosphere of less than 20 ppm (dew point -65°C). This can result in a catastrophic failure mode.

These failure mechanisms are related to the intermediate and power load life tests since both of these contact loads arc and will erode and transfer the gold plating, thereby exposing the silver alloy contact material which is prone to "stick."

Organic Contamination.--There was some evidence of organic contamination of relays that were evaluated. In the case of low level life units, evidence of frictional polymer formation was observed. The level was such that there was no effect on the contact resistance, but rather it acted as a "friendly polymer" since it is a good lubricant. Figures 10 and 11 are photomicrographs of the contact surfaces after 100,000 operations. There is a trace indication of polymer visible. Conduction is through the exposed asperities.

This level of organic contamination, estimated to be of the order of 10-30 ppm, could come from an insufficient vacuum outgassing process as previously described or it could be associated with the hermeticity problems. The level does not indicate that it is a serious problem, particularly when compared to exposed coil contact assemblies.

Discussion.--Due to the large number of catastrophic failures, it was not possible to pursue in detail the effect of particulate contamination on contact performance because of the masking effects of these other mechanisms. Excellent correlation was obtained among the atmosphere, contact wear, leakage, and contact performance as described above. It was demonstrated that a traditional silver based gold plated contact alloy was not capable of reliably operating under extremely "dry" conditions without welding. The inter-relation between some of the critical vacuum outgassing parameters was established and demonstrated.

The results confirmed the fact that the Super J's contact performance was limited by contact materials and not processes as a first order effect. Leakage of the contact module has been upgraded by improved welding and brazing techniques and this is not now a limiting factor.

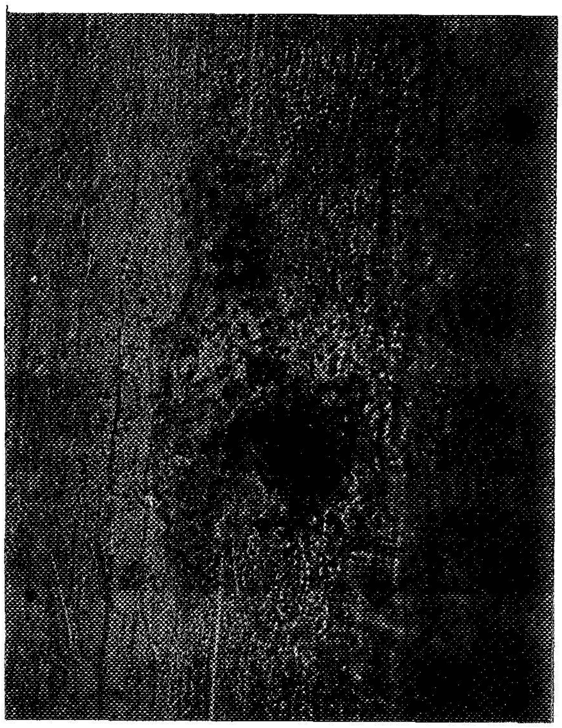


FIGURE 10
150X

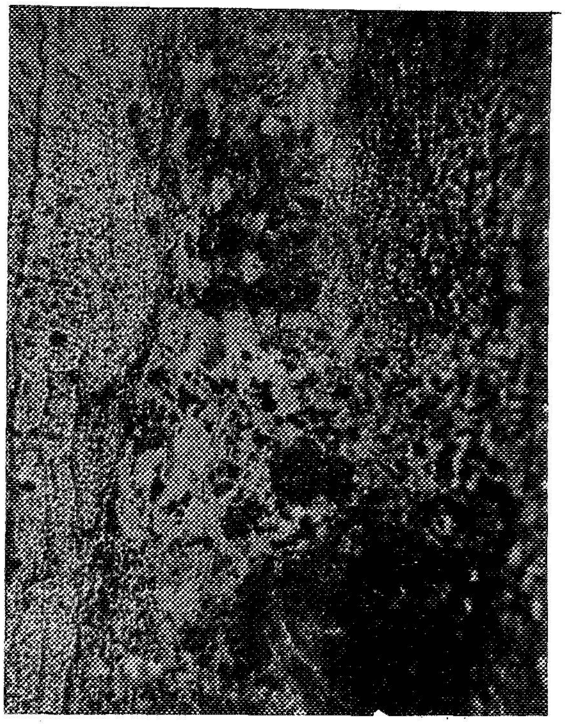


FIGURE 11
300X

Example of Frictional Polymer Formation Showing Trace Amounts of Polymer After 100,000 Operation Low Level Life. Contact Resistance Was Not Affected.

CONTACT MATERIALS

In the last decade, though many advances have been made in the field of relays for the military market, there is little evidence of any substantial improvement in materials for electrical contacts. It would appear that the make-break electrical contact field (in the power range of interest) has borrowed heavily from the dental and jewelry fields and covered up the inherited deficiencies by plating or cladding and by fastening contact buttons on to spring arms.

The trend to microminiaturization and ultra-clean systems has made demands on spring properties, resistance to welding, and contact resistance stability, which the present family of materials has not been able to fulfill.

Table X lists the present standard contact materials used in the relay industry today, categorized by three of the most important criteria:

a) Spring Characteristics - The ability to resist creep or relaxation at stress levels of 40,000 psi and temperatures up to 250°C.

b) Switching Capability - The ability to switch power loads up to 2 amps at 28 V dc for a minimum of 100,000 operations.

c) Contact Resistance Stability - The ability of material to resist film formation which cannot be punctured under the low forces employed and which is stable when switching low level signals.

It is readily seen that all of the materials are deficient in at least one of the criteria and must be either plated, clad, or fastened to a spring member. These additional processing steps imply the necessity of rigorous controls and even under the most careful processing can be sources of contamination.

In an effort to overcome this problem area, the contact material development program's ultimate objective was a monolithic contact material. This monolithic material is a combined high temperature spring and contact material that requires neither plating nor cladding and is capable of switching signals in the low level, intermediate load, and power load regions.

Alloy Selection

Despite the obvious advantages of gold and gold-rich alloys in their passive nature for contact resistance stability, a look at Table X shows them suffering from the basic inability to switch current in the power load region. It would appear that only a fundamental study into the theory of arcing would bear fruition in understanding what type of gold alloy system would be resistant to erosion and metal transfer under power load switching. This type of investigation was beyond the scope of this study.

There remains the silver based and Pt family based precious metal alloys and possible combinations of these. Though the Pt group metals are known to be susceptible to polymer formation due to both friction and activation phenomena, it is felt that use of sealed switching modules will either eliminate entirely or minimize the organic contaminants necessary for the polymer to form.

TABLE X

CONTACT MATERIAL CRITERIA

Material	Spring Characteristics	Contact Resistance Stability	Switching Capability	Remarks
Au	Bad	Excellent	Poor	Welds easily.
92 Au, 8 Ag	Bad	Excellent	Poor	Welds easily.
69 Au, 25 Ag,6 Pt	Bad	Good	Marginal	Used only as a clad overlay.
71.5 Au,4.5 Ag, 14.5 Cu,8.5 Pt, 1 Zn	Good	Poor	Poor	
93.5 Au, 3.5 Ni, 3 Co	Good	Fair to Good	Poor	
Ag	Poor	Good to Excellent	Very Good	
72 Ag, 28 Cu	Fair	Poor	Good	
Ag, 5-20 CdO	Poor	Fair to Good	Very Good	Used exclusively as a button attached to a spring arm.
99.5 Ag, 0.25 Mg, 0.2 Ni	Fair to Good	Fair to Good	Fair	Internally oxidized to attain spring properties.
Pd	Poor	Fair to Good	Fair to Good	Very susceptible to polymer formation.
35 Pd, 30 Ag, 10Pt, 10 Au, 14 Cu, 1 Zn	Excellent	Poor	Marginal	

Though many binary and ternary alloys of Ag and the Pt group can be hardened by cold working to fairly high yield strength values, it is common knowledge that strengthening by virtue of a dispersed phase is far more resistant to creep and relaxation at elevated temperatures. This was shown by Barker (Ref. 12) for precious metal alloys.

One additional undesirable trait that generally occurs with use of solid solution strengthening additives is that of a rapid decrease in conductivity. Linde (Ref. 13) reported that even minor additions of 2-3 atom % of some elements could result in a 3-4 fold increase.

Dispersion strengthening can be accomplished in several ways: e.g. powder metallurgy techniques, internal oxidation, precipitation hardening, etc. The first two are quite common techniques employed in the manufacture of electrical contacts today. The powder metallurgical process presents interesting possibilities for studying systems that cannot be made by any other means. Internal oxidation has been used extensively for strengthening of silver and aluminum for some time. It has been explored to some degree by Vines (Ref. 14) for electrical contact applications. Both of these techniques, due to the kinetics and specialized facility, were beyond the scope of this study.

Age Hardenable Alloys.--Dispersion hardening by precipitation of a second phase through heat treatment is a common technique used in metal fabrication. Many tool steels and spring materials are hardened in this manner. An examination of the equilibrium phase diagrams (Ref. 15) of the binary alloys of silver and of the Pt group metals reveal the following systems to have terminal solid solutions which could permit precipitation hardening:

Ag - Al
Ag - Be
Ag - Cu
Ag - Mg
Ag - Mn
Ag - Pt
Pd - Be
Pd - Al

Ishida and co-workers (Ref. 16) explored the use of Al to temper Ag and found hardness readings in excess of 350 Vickers could be obtained. Likewise, Darken (Ref. 17) showed that yield strengths in excess of 60,000 psi could be obtained with Ag containing 0.5% Al that was oxidized. The Ag-Be system appeared promising in its similarity to the Be-Cu and Be-Ni systems which are well known spring materials. The use of Ag-Cu is well known in the contact field, particularly for its high conductivity. The Ag-Mg phase diagram bears a basic similarity to the Ag-Al phase diagram with the additional feature of an order-disorder transformation in the solid state. The Ag-Mn system for electrical contacts appears to have interest to the

Russians, and a patent (Ref. 18) was issued in 1964. Ag-Pt has obvious advantages in that one would not expect oxidation problems and might act as Pd in reducing the tendency of Ag to tarnish. Both the Pd-Be and Pd-Al systems showed terminal solid solubility (Be to a very limited extent) and were of interest.

The Silver-Pd system appeared to be a good starting point for a ternary system. The system shows complete solid solubility. Additions of up to about 30% Pd in silver will noticeably increase physical properties, tarnish resistance, and resistance to metal transfer while still retaining acceptable electrical conductivity. Additions of Cu to the Ag-Pd system have been the basis for a series of high strength brazing alloys. (Ref. 19) The system also becomes hardenable by virtue of order-disorder transformation and precipitation of copper and silver rich phases. These are accomplished with very little sacrifice in electrical conductivity. Addition of Mn to the Ag-Pd system has also resulted in high temperature brazing alloys. (Ref. 19) Whereas Mn shows a high degree of solubility in both Ag and Pd, this is markedly reduced in the ternary system and precipitation hardening could be accomplished with minor addition. The same is true with addition of Al to the Ag-Pd system where minor addition should accomplish precipitation hardening. (Ref. 19) While Be is only sparingly soluble in both Ag and Pd, Feduska (Ref. 20) has shown that minor additions of Be (up to 1.15%) in a Ni-Pd solid solution increases the hardness markedly. The same effect may be obtained with the Ag-Pd solid solution alloy.

Silver was chosen as the base metal for the experimental contact alloys, and large palladium and platinum additions were made for tarnish resistance and solid solution strengthening. The literature was reviewed to select ternary element additions which possessed limited solubility in silver at low temperature with a more extensive solubility at elevated temperature. This is a basic characteristic of age hardening alloy systems. The number of such silver alloy binary systems published in the literature is very limited and only one or two ternary isotherms could be found, including those which suggested hardening possibilities based on isolated mechanical properties tests. (Ref. 15, 20-24). Five such ternary additions were selected. These, in combination with palladium and platinum binary combinations with silver, gave ten master ternary alloys. A final silver-platinum-palladium ternary was also selected. Approximate ternary isotherms were constructed where possible and three compositional variations of each ternary addition were made in hopes of straddling the solid solution-two phase boundary at the solution annealing temperature. For silver base alloys, this is in the range of 800-900°C. An example of one of the constructions is shown in Figure 12. The ternary isotherm shown in the construction is a composite of the phase boundaries expected at 400°C and 780°C. The 33 alloys that were selected using this procedure are listed in Table XI.

FIGURE 12

EXAMPLE OF TERNARY ALLOY ISOTHERM CONSTRUCTION

BASED ON BINARY ALLOY DIAGRAMS

Ag-Pd-Cu System

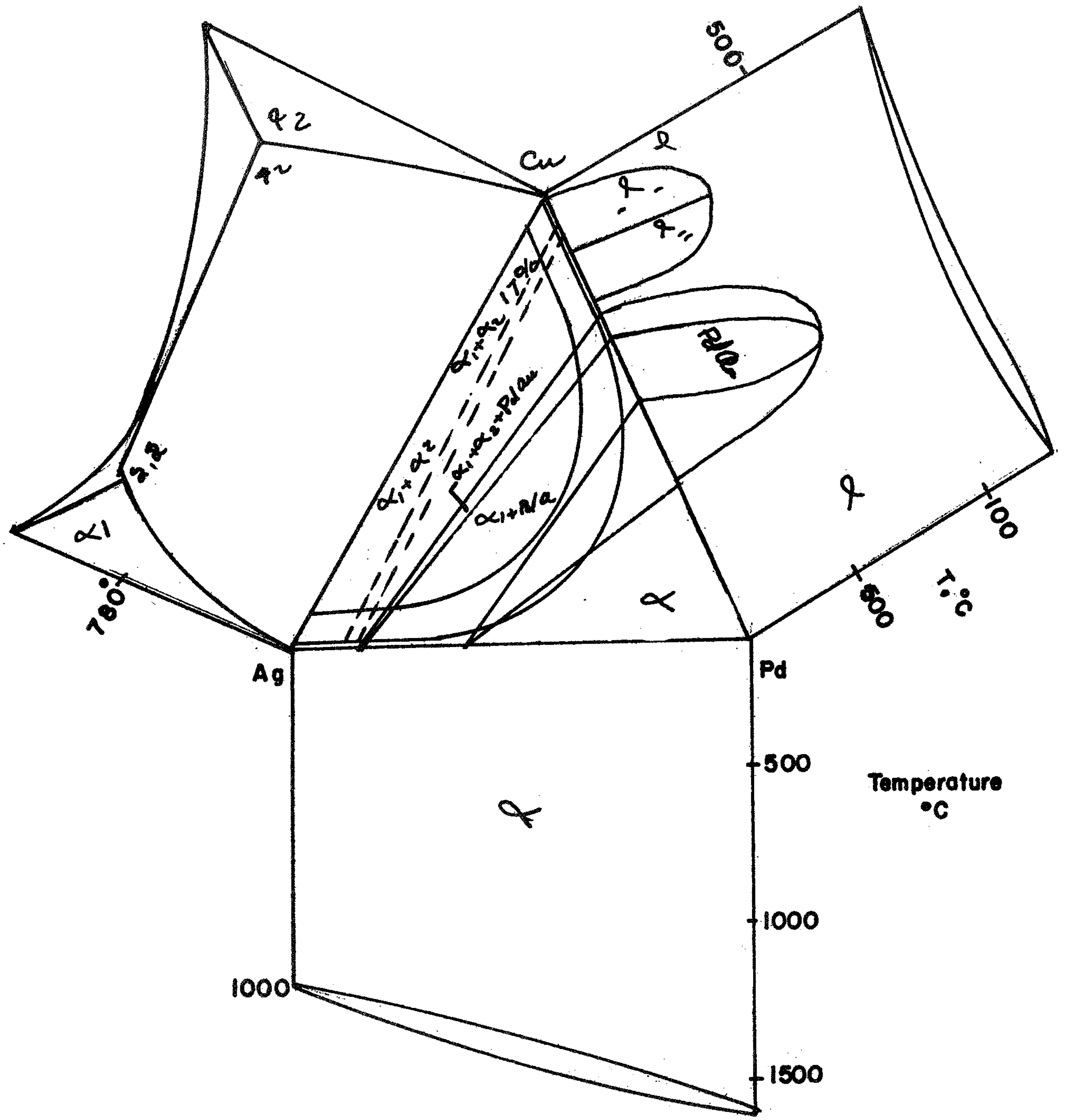


TABLE XI

ALLOY COMPOSITIONS

Alloy No.	Base Weight %	Minor Addition Weight %
1 A	Ag - 17 Pd	8.0 Cu
B	"	5.0 Cu
C	"	2.0 Cu
2 A	Ag - 30 Pd	5.0 Mn
B	"	3.0 Mn
C	"	1.0 Mn
3 A	Ag - 20 Pd	5.5 Al
B	"	4.0 Al
C	"	8.0 Al
4 A	Ag - 20 Pd	8.0 Mg
B	"	4.0 Mg
C	"	1.0 Mg
5 A	Ag - 20 Pd	0.3 Be
B	"	0.1 Be
C	"	0.05 Be
6 A	Ag - 15 Pt	7.5 Cu
B	"	5.0 Cu
C	"	2.0 Cu
7 A	Ag - 15 Pt	5.0 Mn
B	"	2.0 Mn
C	"	0.5 Mn
8 A	Ag - 15 Pt	5.5 Al
B	"	4.0 Al
C	"	2.0 Al
9 A	Ag - 15 Pt	7.0 Mg
B	"	3.0 Mg
C	"	1.0 Mg
10 A	Ag - 15 Pt	0.3 Be
B	"	0.1 Be
C	"	0.05 Be
11 A	Ag - 10 Pd - 30 Pt	
B	Ag - 10 Pd - 22 Pt	
C	Ag - 20 Pd - 25 Pt	

Melting and Fabrication

Six vendors were asked to quote on the melting and fabrication of the 33 alloys. They were asked for a minimum 2 troy ounce ingot of each composition, 1.75 ounces of which would be rolled into 0.014 inch thick x 0.0825 inch wide strip and the remainder drawn or swaged into 0.015 inch diameter wire. It was felt that this would result in approximately 18-20 feet of wire and strip.

The vendors were asked to hold to the design compositions within tight limits and to limit the total impurity content to 0.1% or less. The necessity of good homogeneity in an age hardening alloy and the fact that the cast structure would have to be broken down with working-annealing cycles were stressed.

Only two vendors responded, one with a very high fixed fee and the other, Materials Research Corporation, Orangeburg, N.Y., offered a best effort type arrangement. This latter offer was selected as the most feasible, and the work was divided into two phases. In the first phase, MRC melted, using vacuum induction and/or gas covered arc melting techniques, 11 master alloys of each ternary system. The compositions were checked, and an initial fabricability check was made. Errors in the composition or segregation were adjusted by remelting. Once sound ingots were obtained, 30-50% swaging reductions were performed. Those alloys which could be successfully worked were then selected for additional work in phase two. The ingots were divided in thirds with two parts being further diluted with the silver binary addition to form the remaining compositions of each ternary alloy. All the melts were then reduced to the final strip and wire dimensions utilizing intermediate anneals where necessary. Final chemical analyses were also performed on those alloys which were selected for complete testing.

Most of the ingots required remelting by MRC to improve uniformity and homogeneity. In general, the final melt consisted of a 20 minute induction melt followed by a cooling down of about 10 minutes to 300°C in vacuum or a partial atmosphere of argon. The aluminum and magnesium containing alloys resulted in either unsound ingots or were not possible to fabricate. The remaining alloys exhibited varying degrees of fabricability and were continued into phase two. During processing of this phase, several more ingots were dropped because of cracking and other indications of poor fabricability. The remaining alloys, the fabrication results, and chemical analyses, where determined, are listed in Table XII. Dissolution of many of the alloys for wet chemical analysis proved somewhat difficult. In particular, the alloys containing approximately 15% platinum resisted the attack of all the normal reagents.

The strip was produced by drawing the swaged ingot down to

TABLE XII
MELTING AND FABRICATION RESULTS

Alloy No.	Chemical Analysis (Master)			Fabrication History
	Element	Top	Bottom	
1A	Ag	74.7	78.7	reduced without difficulty
	Pd	14.8	11.7	
	Cu	7.3	8.1	
1B,1C	bottom 2/3 of 1A Diluted to form			same as 1A
2A	Ag	67.8	70.3	cracked while swaging
	Pd	29.2	30.9	
	Mn	5.6	3.1	
2B	bottom third of 2A used			reduced with repeated anneals
2C				no difficulty
5A	Ag	90.2	69.7	cracked in fabrication despite remelting and annealing
	Pd	9.6	29.8	
	Be	0.17	0.46	
5B,5C	obtained by dilutions of 5A			reduced with repeated anneals
6A	Ag	85.5	45.4	remelted twice; middle of ingot reduced after annealing
	Pd	6.3	51.2	
	Cu	7.2	3.3	
6B,6C	remainder of 6A diluted to form			reduced with intermediate anneal
7A	Ag	81.4	80.9	remelted; did not fabricate
	Pt	13.3	13.4	
	Mn	5.2	5.6	
7B	obtained by dilution of 7A			did not fabricate
7C	new melts			reduced after initial anneal
10A	Ag	90.1	65.8	middle of ingot reduced after initial anneal
	Pt	9.6	33.9	
	Be	0.28	0.22	
10B,10C	new melts			reduced after initial anneal
11A	Ag	66.9	62.3	middle of ingot reduced after initial anneal
	Pt	23.8	30.0	
	Pd	9.2	7.7	
11B	Pd added to remainder of 11A			reduced with repeated anneals
11C	additions made to 11B			cracked despite anneals

approximately 0.050 inches in diameter and then rolling to the final thickness. Some of the strip had a considerable camber problem in addition to rough edges and, in some instances, localized peeling form segregation in the ingot.

It is felt that better fabrication techniques could have been utilized, and stricter attention to annealing cycles might have resulted in more successfully fabricated alloys.

Mechanical and Physical Properties

Sixteen of the original thirty-three alloys were workable into strip and wire. These alloys were tested for their properties after various heat treatments. As indicated earlier, age hardening alloys must first be given a solution anneal followed by a rapid cooling down to room temperature. The optimum solution anneal is that temperature at which the maximum concentration of the alloying elements can be dissolved in solid solution. It can be seen from the appropriate binary phase diagrams of silver base alloys that this temperature lies in the range of 750-950°C. At these temperatures, diffusion rates in single phases are rapid enough so that two hours are more than sufficient to achieve homogeneity. The rapid cooling normally is achieved by quenching into cold water. Since heating to these temperatures and quenching into cold water would severely oxidize the sample, a system was devised to conduct this heat treatment cycle in a protective atmosphere.

A manifold connected to an oil diffusion pump system capable of 10^{-5} torr was constructed. The samples to be annealed were degreased and electrolytically cleaned and then placed in a quartz tube sealed at one end and with a constriction on the other end. These quartz tubes were then placed on the manifold and evacuated as shown in Figures 13 and 14. A partial atmosphere of pure helium was introduced into the system for better heat transfer and then the capsules were sealed at the constrictions with an oxy-acetylene torch. The encapsulated samples could then be safely annealed, quenched and subsequently aged.

The aging temperature should generally be as low as possible due to the Kinetics of the second phase precipitation. However, it must be significantly higher than subsequent service temperatures to avoid the possibility of over aging. It was decided to study the aging Kinetics in the range of 350-400°C. The aging time was varied over 0.5, 1, 2, and 4 hours.

The first round of heat treatments were run with solution anneals from 780°-950°C with the time varying inversely with the temperature from one to two hours. The 950°C anneal was used on the Ag-Pd-Pt alloy since it was felt that the diffusion Kinetics

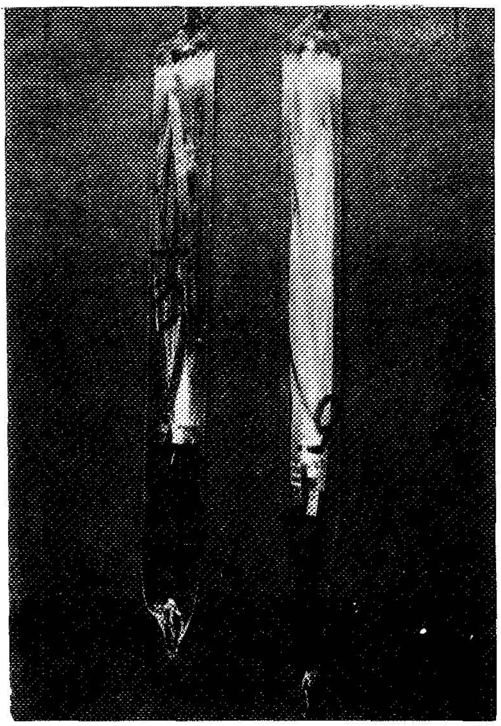


FIGURE 13
Quartz Heat Treating Tubes
For Contact Strip Alloys

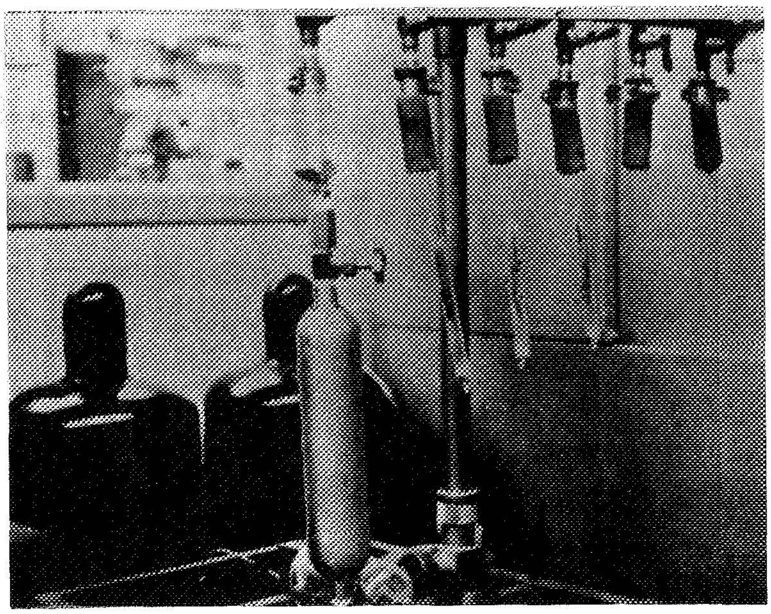


FIGURE 14
Quartz Tube Vacuum & Backfill
System Used to Backfill
Inert Atmosphere Into Tubes

in this system were the slowest and there was no possibility of a reduced melting point.

All the initial aging treatments were run at 400°C from 0.5 to 2 hours. The response to these heat treatments was followed by testing 3.5 inch long strip samples on an Instron tensile tester. The flow stress, tensile stress, and elongation in one inch were determined. The data for aged material after the optimum initial aging treatment are given in Table XIII.

The alloy 10 series (Ag-Pt-Be) samples blistered during the heat treating and, to a lesser extent, alloy 11A (Ag-Pt-Pd) also appeared to peel upon examination after heat treatment. Metallographic examination revealed the presence of rolled-in impurities, probably organic lubricating material, in the alloy 10 strip. Alloy 11A, on the other hand, appeared to be grossly segregated in localized portions of the strip. There was evidence of minor segregation in a number of the alloys. While it is possible that some of this segregation may have been the precipitation of additional phases, the morphology was such that one could be reasonably certain in identifying the constituent as impurities or macro-segregation. Examples are shown in Figures 15 and 16.

TABLE XIII

MAXIMUM MECHANICAL PROPERTIES AFTER INITIAL HEAT TREATMENT

Alloy	Heat Treatment	Flow Stress ($\times 10^3$ psi)	Tensile ($\times 10^3$ psi)	Elongation,%	Hardness HK500**
1A	780°C, 2 hrs, Q* & 400°C, 1/2 hr	69.0	109.3	38.1	233
1B	780°C, 2 hrs, Q* & 400°C, 1/2 hr	77.5	104.2	33.2	212
1C	780°C, 2 hrs, Q* & 400°C, 1/2 hr	22.1	46.7	74.5	136
2B	900°C, 1 hr, Q* & 400°C, 1/2 hr	38.0	70.0	40.3	131
2C	900°C, 1 hr, Q* & 400°C, 1/2 hr	25.6	55.8	54.8	107
5B	880°C, 1 1/2 hr, Q* & 400°C, 1/2 hr	16.0	42.8	58.9	109
5C	880°C, 1 1/2 hr, Q* & 400°C, 1/2 hr	15.0	36.1	48.5	83
6A	780°C, 2 hrs, Q* & 400°C, 1/2 hr	18.6	28.9	12.1	64
6B	780°C, 2 hrs, Q* & 400°C, 1/2 hr	18.4	23.5	5.2	39
6C	780°C, 1 hr, Q* & 400°C, 1/2 hr	24.3	43.2	56.7	93
7C	900°C, 1 hr, Q* & 400°C, 1/2 hr	5.8	23.7	40.5	52
10A	880°C, 1 1/2 hr, Q* & 400°C, 1/2 hr	8.0	23.2	26.6	43
10B	880°C, 1 1/2 hr, Q* & 400°C, 1/2 hr	8.2	29.1	68.3	46
10C	880°C, 1 1/2 hr, Q* & 400°C, 1/2 hr	8.7	30.5	47.5	52
11A	950°C, 1 hr, Q* & 400°C, 1/2 hr	22.8	53.7	42.5	76
11B	950°C, 1 hr, Q* & 400°C, 1/2 hr	36.1	63.6	30.4	178

*Q Quenched

**HK500 Knoop at 500 gm

FIGURE 15
300X,Alloy 10A(Ag-Pt-Be),
Example of Impurities or
Macro-Segregation

FIGURE 16
300X, Alloy 11A(Ag-Pt-Pd),
Example of Internal Cracking and Probable Cause of
Blistering Resulting From
Contamination.

Alloys 1C, 5B, 5C, 6C, 7C, 10A, 10B, 10C and 11A did not respond mechanically to the various aging treatments after the initial solution anneal and were dropped from further development. However, some other physical properties were determined on a few of these alloys.

Based on the tensile strength data and microstructures, a second round of samples of the remaining alloys was solution annealed at 800,900, or 950°C and subsequently aged at 350-400°C for times up to 4 hours. Wire samples were also included for electrical resistivity measurements. In addition to tensile testing straight strip, round notch tensile specimens were also tested to determine the effect of any (sharp) notch sensitivity. Pieces of strip of these remaining alloys were also checked for microhardness. The tensile and hardness data obtained after the final optimized heat treatment are listed in Table XIV. The electrical resistaivity data are given in Table XV.

Based on data given in these tables, alloys 1A, 1B and 2B were selected for further work in subsequent phases of the pro-

TABLE XIV

MECHANICAL PROPERTIES AFTER OPTIMIZED HEAT TREATMENT

Alloy	Heat Treatment	Flow Stress ($\times 10^3$ psi)	Tensile Strength ($\times 10^3$ psi)		Elongation,%	Hardness (Knoop-500 gm)
			Uniform	Notched		
1A	800°C, 2 hr, Q*	30.9	60.2	----	60.0	169
	Anneal & 350°C, 1 hr	72.1	110.5	124.0	14.5	235
1B	800°C, 2 hr, Q	28.6	54.9	----	68.5	109
	Anneal & 350°C, 1 hr	88.1	108.0	123.6	28.0	233
2B	900°C, 1 hr Q	34.4	52.7	----	19.3	124
	Anneal & 400°C, 4 hrs	37.9	63.5	83.3	25.0	139
2C	900°C, 1 hr Q	24.6	54.0	----	66.5	90
	Anneal & 400°C, 4 hrs	27.7	57.8	65.5	61.3	104
6A	900°C, 1 hr Q	16.7	31.5	----	20.0	65
	Anneal & 350°C, 2 hrs			60.1	10	130
6B	900°C, 1 hr Q	18.8	27.0	----	8.3	88
	Anneal & 400°C, 2 hrs			61.2	4	137
11B	950°C, 2 hrs Q	35	65	80.7	35	135
	Anneal & 400°C, 1/2 hr	36.1	63.6	82.8	30.4	178

*Q Quenched

TABLE XV

ELECTRICAL RESISTIVITY DATA

Alloy	Resistivity (micro-ohm centimeter) Solution Annealed	Aged
1A	10.4	9.4
1B	13.0	11.6
2B	18.3	17.3
2C	18.1	18.6
6A	9.8	----
6C	13.8	13.2
11B	45.1	46.0

gram. While alloy 2B did not meet the criterion of 100,000 psi tensile strength minimum, it did show a considerable response to the aging treatment. While beyond the scope of this program, additional thermomechanical treatments of these alloys may considerably increase their strength. For example, cold working the annealed and quenched strip while forming it to a final part dimension and then aging the worked part would be expected to result in enhanced strength.

The moduli of elasticity of alloys 1A, 1B and 2B were also determined and are 11.2 x 10^6, 11.3 x 10^6 and 13.3 x 10^6 psi, respectively. Each of these data is the average of six determinations.

Typical microstructures of these three alloys are shown in Figures 17, 18 and 19, respectively. It should be noted that the coherent precipitate particles responsible for age hardening are not visible at light microscope magnifications. The most satisfactory etchant found for these alloys is a 50-50 solution of potassium cyanide and ammonium persulphate.

Stress Relaxation Tests

Relaxation tests were performed at 200 and 250°C for times up to six hours, with preset stresses of 20,000 and 40,000 psi. Alloys 1A and 1B (AgPdCu), 2B and 2C (AfPdMn), and 11B (AgPdPt) were initially tested. Due to their low yield strength at room temperature, alloys 2C and 11B were dropped from the final series of tests. Specimens were mounted as a propped cantilever spring of nominal 0.015-inch thickness, 0.085-inch width and effective spring lengths of 0.500 inch. Force was applied by a set screw at the prop location so as to produce the required stress levels. The entire eight station, expansion matched, stainless steel fixture was placed in an Instron Temperature Chamber mounted on an Instron Tensile Tester. Changes in the preset force were used

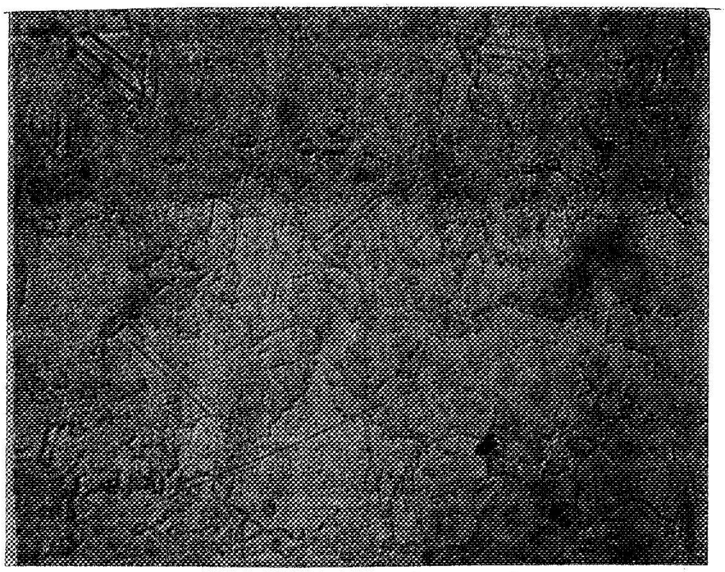


FIGURE 17
300X, Alloy 1A (Ag-Pd-Cu), Microstructure After Optimum Heat Treatment (800°C, 2-hours, Quenched, Plus 350°C for 1-hour).

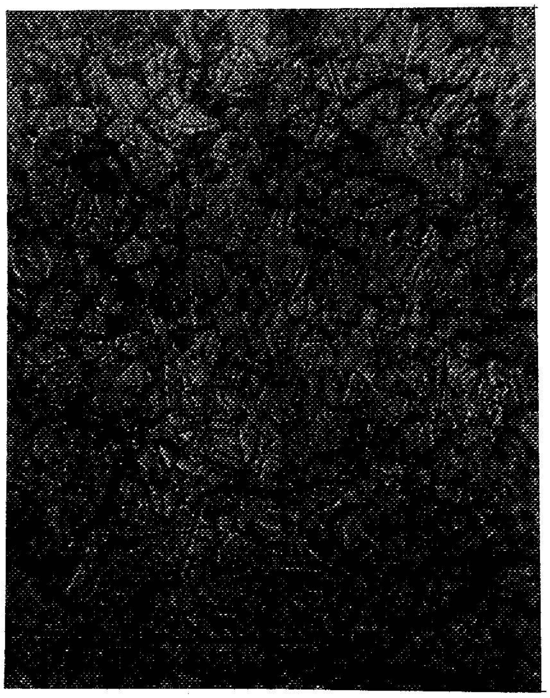


FIGURE 18 300X

FIGURE 19 1100X

Alloy 1B (Ag-Pd-Cu), Microstructure After Optimum Heat Treatment (800°C, 2-hours, Quenched Plus 350°C for 1-hour) as an indication of relaxation. A regression equation was developed for the data in the form:

$$\%L = A - B \ln (t) \qquad (1)$$

where %L = percentage change in load
A = intercept constant
B = slope constant
t = time, minutes at temperature

Data were obtained from 2-4 samples per run. Table XVI is a summary of the experimental constants for alloys 1A, 1B, and 2B, the strongest alloys. The $\% L(t_{RT} - t_{TT})$ is an extrinsic factor resulting from adjustments in the stress as the specimen and fixture warmed up.

The constant A involves factors such as thermal adjustments of the fixture in reaching equilibrium and short time, high rate relaxation occurring in the specimen while reaching test temperature. The constant B represents a steady state rate and the slightly higher values obtained at the lower stress levels indicate that the initial rapid relaxation stage was larger at the 40,000 psi stress level. This conclusion is borne out by most of the A values.

In evaluating the data, the significant parameters were found to be the slope parameter B and the fact that a maximum of 4-5% permanent loss of load was obtained for these alloys upon returning to room temperature. These tests indicate that the 1A and 1B (AgPdCu) alloys are highly resistant to stress relaxation at temperatures up to 250°C and that the long term steady state creep rate is also quite low.

Contact Resistance Tests

The most promising alloys from the standpoint of strength were the AgPdCu group (1A and 1B). In order to determine their contact resistance and to develop optimized precleaning procedures, an ASTM type microcontact tester was utilized. The tester is described in ASTM B-326-67. The 0.015 inch diameter wire specimens were cleaned and placed in the tester in "cross-rod" geometry. This configuration eliminates the influence of the bulk resistance and connecting wire resistance. A Keithley model 503 milliohm meter was used to obtain the contact resistance measurements. Fine gold wire 0.002 inches in diameter was used to attach the voltage probes to the outer extremities of the crossed contacts.

Contact resistance versus force data was obtained in the 0.1 to 3.0 gram range. The 1, 2, and 3 gram forces are considered as more significant since lower force measurements are susceptible to vibration and other sources of error. In all cases, a 24K gold wire was used as a comparison standard. Measurements after four different cleaning techniques were made to ascertain an optimum treatment to remove residual organic surface contaminants or "tramp type" contaminants from the contact surfaces. Table XVII. is a summary of the results.

TABLE XVI

STRESS RELAXATION DATA

Alloy	Temp (°C)	Stress ($\times 10^3$ psi)	Experimental Constants A	Experimental Constants B	% $L(t_{RT}-t_{TT})$
1A (AgPdCu)	200	20.0	3.10	1.275	5.5
		40.0	0.43	1.225	4.7
	250	20.0	-3.10	2.580	5.2
		40.0	1.64	2.250	8.8
1B (AgPdCu)	200	20.0	-1.11	1.385	3.7
		40.0	2.74	1.27	6.3
	250	20.0	-2.30	2.50	4.2
		40.0	1.83	2.22	8.6
2B (AgPdMn)	200	20.0	3.73	0.251	2.2
		30.0	5.35	0.612	6.7
	250	20.0	3.46	0.730	5.1

TABLE XVII

CONTACT RESISTANCE FOR AgPdCu ALLOYS (1A & 1B) AFTER FOUR DIFFERENT CLEANING TECHNIQUES

	Cleaning Procedure*							
Force	1		2		3		4	
(Gm.)	1A	1B	1A	1B	1A	1B	1A	1B
1.0	22**	255	29	21	26	20	98	34
2.0	14	85	16	16	16	14	47	22
3.0	11	71	14	15	12	13	34	19

*Cleaning Procedure

**Readings in milliohms

1. NH_4OH - H_2O_2 etch
2. Alkaline cleaner, KCN etch (4 minutes), H_2SO_4 dip
3. Same as 2 except ultrasonically cleaned in Freon TF menthanol at completion.
4. Same as 2 except 1-minute KCN etch.

Comparison of the experimental measurement to the theoretical constriction resistance measurements was made using Holm's relationship shown in eq. 2.

$$R_C = Kp \left(\frac{H}{P}\right)^{1/2} \qquad (2)$$

where K = geometry and unit constant, $2.5(10^{-5})$
p = resistivity (ohms-CMF)
P = force (gm)
R_C = constriction resistance (ohms)
H = Brinell hardness

Relatively good agreement was obtained above 1 gram as shown in Table XVIII for alloys 1A and 1B after the type 3 cleaning procedure. Based on these tests, the type 3 cleaning procedure was applied to all the alloy 1A and 1B formed contacts prior to assembly into relays.

TABLE XVIII

COMPARISON OF MEASURED AND CALCULATED CONTACT RESISTANCE

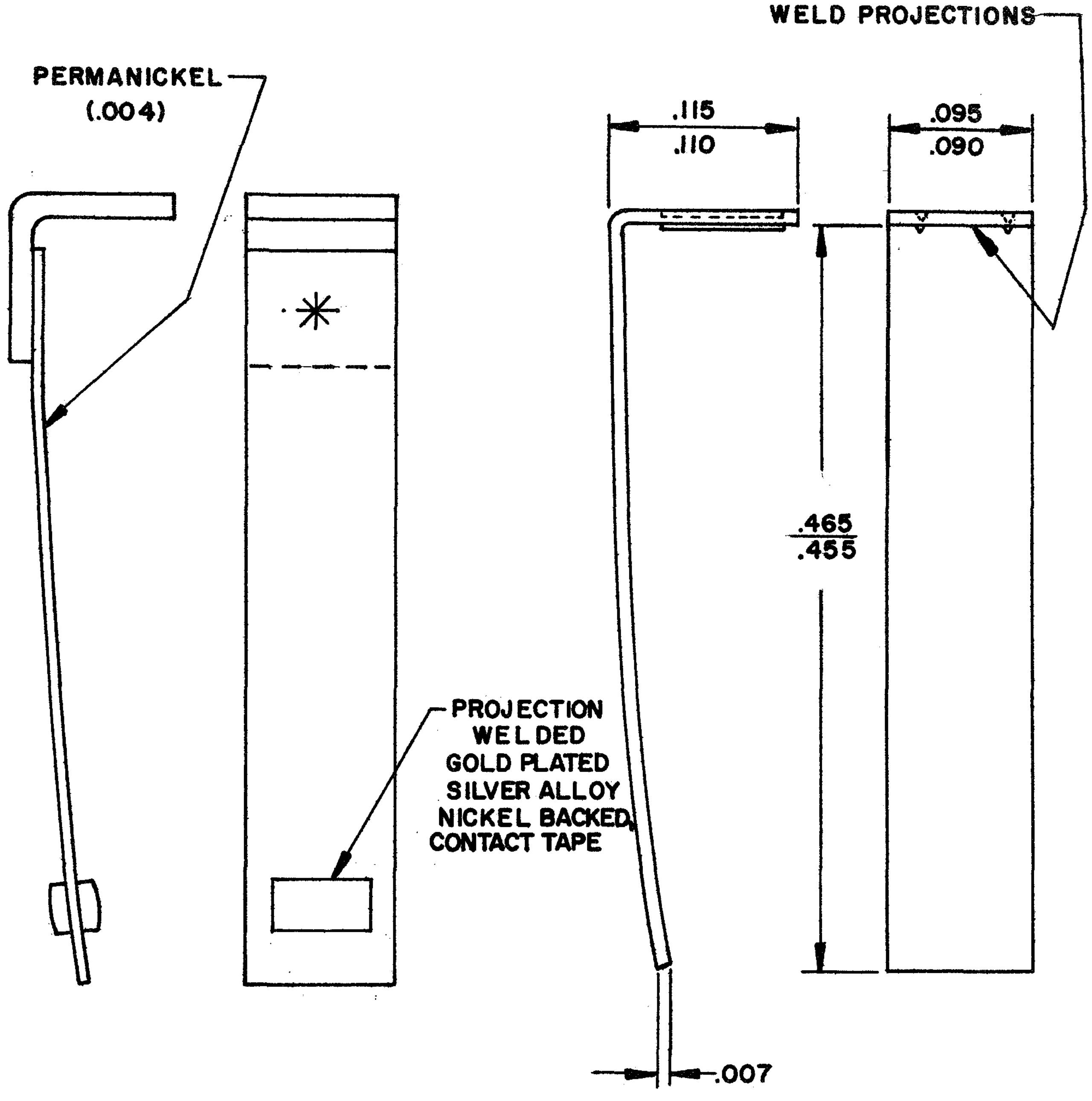
	Contact Resistance ($\times 10^{-3}$ ohms)			
	Alloy 1A		Alloy 1B	
Force (gm)	Measured	Calculated	Measured	Calculated
1.0	26	19	20	23
2.0	16	13.5	14	16.5
3.0	12	11	13	13.5

Contact Fabrication

Monolithic Contacts.--Alloys 1A and 1B, nominal composition Ag-17Pd-8Cu and Ag-17Pd-5Cu, respectively, were selected for additional contact performance tests in Super J relays. Both the fixed and the movable contacts were made from the same material that was used to determine the mechanical and physical properties.

In order for an accurate comparison to be made between the standard gold plated, silver alloy, tape-type contact system and the monolithic contact system, it was necessary for the monolithic type to have identical spring rates, contact forces and wipe. It was experimentally determined and verified by calculations that a 0.007-inch thick movable arm would be equivalent to the standard contact system. The experimentally determined movable arm rate was 0.80 gm/mil-inch. Figure 20 is a comparison between the monolithic design and the standard contact assembly.

The fixed contacts were formed from the 0.015 inch thick material. The strip was cut into 4-6 inch lengths and solution



STANDARD CONTACT ASS'Y

MONOLITHIC CONTACT

Figure 20 STANDARD AND MONOLITHIC MOVABLE CONTACT ASSEMBLIES.

annealed in the quartz tube furnace prior to forming the 90° bend, weld projections, and contact surface radii. After forming, the fixed contacts were cleaned and subjected to the optimized heat treatment prior to assembly into headers.

A portion of the same 0.015 inch strip material was reduced to nominal thickness of 0.007 inches in a two high mill. The reduced contact strip was solution annealed and formed into monolithic contacts with weld projections and pre-form bend. After cleaning, the contacts were subjected to the optimized heat treatment. In the hardened condition, it was not possible to form the sharp 90° bends without cracking the material and introducing excessive residual stresses. By using these procedures, a minimal residual stress, associated with adjusting the headers, was left in the materials.

Prior to assembly into headers, the contacts were given a type 3 cleaning (Alkaline clean, KCN etch-four minutes, H_2SO_4 dip followed by ultrasonic cleaning in Freon TF). No major problems were encountered in the fabrication of these contacts.

Rhodium Plated Contacts.--Based on the performance tests that were conducted on the standard gold plated silver alloy contacts and the associated cold welding that occurred after the silver substrate had been exposed by wear through the gold plate, another group of relays using rhodium plated fixed contacts was fabricated for comparison. It was hypothesized that a hard wearing surface over the soft silver alloy substrate would be sufficient to minimize the wear through to the silver and hence inhibit the cold welding effect. Electrodeposited rhodium was selected due to its high hardness and excellent wear properties.

The specific system that was used on these experimental groups was SEL REX'S Rhodex rhodium plate. This system is a low stress, crack-free rhodium electrodeposit with hardness of 800-900 Knoop as opposed to 175-225 Knoop for the gold plate.

Two groups of 500 fixed contacts each were barrel plated to the following specifications: 100-200 micro-inches rhodium (Rhodex) over 10-20 micro-inch gold over $99A_g$-$1P_d$ substrate. One group was plated as indicated while the other group received an additional 20 micro-inch (max.) high purity gold over plate. This additional gold over plate was for purposes of lubricity and improved contact resistance stability. Measurements of thickness, adhesion, and heat resistance (220°C) were performed to assure conformance to the specification. No major discrepancies were noted.

Manufacture of Test Relays

Three groups of Super J relays were manufactured using the experimental contacts. The manufacturing parameters were identical in all groups and comparable to those used during the first phase of the program. The major manufacturing problem was similar to those encountered in the first phase, namely, leakage of the contact module during the assembly operations. In all cases, gross leakers in the order of 10^{-5} to 10^{-6} atm. cc/sec of Helium were removed from the test groups. This, in general, accounted for the majority of the rejects encountered during the manufacturing phases.

There were no sealant materials used on the header assembly at any stage of manufacture; however, as a standard parctice, resin sealant was used on the core and coil feedthru area which acted as a moisture barrier between the coils and the feedthrus. The leakage, in general, was associated with the braze operation and coil feedthru rather than the header assembly. It was noted that the final solder dip operation, which involved a fluxing and soldering of the header and terminal pins for corrosion protection and improved solderability, did, in some cases, reduce fine leaks associated with the header to a non-detectable level. This was probably due to the action of the flux acting as a sealant. Subsequent contact resistance measurements did not reveal any indications that the flux was entering the contact chamber.

No attempt was made to modify the vacuum outgassing cycle that was developed for the gold plated silver alloy contact relays since this would compound the number of variables. The procedure used during the manufacture of all of the experimental contact material relays was the 170±10°C, 90-minute, 10^{-2} torr max., less than 20 ppm water vapor cycle. This cycle, as previously discussed, was designed to yield a high, but acceptable residual water vapor level inside the contact module.

<u>Monolithic Contact Relays</u>.--Two lots of Super J relays were manufactured using alloy 1A (Ag-17Pd-8Cu) for lot 24 and alloy 1B (Ag-17Pd-5Cu) for lot 25. A total of 93 relays were manufactured with an overall yield of 84% (78 test relays). The major loss was due to leakage as previously discussed.

As a result of a change in the contact material, new header welding schedules had to be developed. It was not possible to produce an optimized weld schedule due to the limited number of the contacts available. The approach taken was to produce secure welds without particular regard to weld flash or ultimate strength. It was felt that the contact material weldability could be a major factor in mass production assembly using these alloys unless a closer resistivity match between the terminal pins and contact material could be obtained. There was no noticeable difference between the weldability of alloys 1A and 1B.

Erratic contact resistance was encountered during the final cleaning operations prior to vacuum outgassing. Contact resistance variations in excess of 5 milliohms were found on approximately

80% of all units, and contact resistances greater than 30 milliohms were encountered on over 40% of all units. This effect was independent of the number of times the units were ultrasonically cleaned. The contacts in these units had been precleaned using the type 3 procedure listed in Table XVIII. Apparently, the contact surfaces were tarnished during the manufacturing operations. Since this variation in the norm was encountered during the early assembly stages of these two lots, a modified type 3 cleaning procedure was used on the remaining contacts. The remaining contacts, approximately 70%, were cathodically cleaned and then given a long etch in a hydrogen peroxide solution until bright, rinsed, and six-step cleaned in the ultrasonic Freon system. Greatly improved stability was obtained. The nature of this tarnish film is unknown, but the contact resistance variation disappeared after the subsequent vacuum outgassing process which suggests low stability and, therefore, should not be a problem in sealed relays.

No major problems, other than the two mentioned above were encountered during the manufacture of these two lots of monolithic contact relays. The units are considered as representative of Super J relays manufactured at that time period.

Rhodium Plated Contact Relays.--Four lots, totaling 93 test relays, of the rhodium plated contacts were manufactured into Super J relays. The four lots, numbered 17, 19, 21 and 23, were divided into groups of 10, 10, 8, and 3, respectively. These small groups of relays were manufactured concurrently with those used in the Process and Contamination Phase of the study, thereby providing controlled comparison standards. Table XIX summarizes the number of lots and their features.

TABLE XIX

SUMMARY OF RHODIUM CONTACT LOTS MANUFACTURED

Lot	Group	Test Relays	Features
17	10	30	Rh over Au plate fixed contacts
19	10	25	Au over Rh over Au plated fixed contacts and modified motor assy. (experimental braze alloy)
21	8	17	Au over Rh over Au plate fixed contacts
23	3	21	same as lot 21

These rhodium plated fixed contacts were mated against the standard gold plated, silver alloy substrate movable contact assemblies used in the first phase of the study. The use of barrel plated fixed contacts resulted in a difficult welding operation of the contacts to the header terminal pins. The rhodium plate has a very high melting point, approximately 2,000°C, and this, coupled with the inherent resistivity mismatch between the nickel backing on the fixed contacts and the 52 alloy terminal pins, resulted in welds with excessive flash and minimal security. This problem was not unexpected since it had been evaluated during the initial phase of the study. The purpose of these experimental alloys was not to resolve these associated problems, but rather to demonstrate the feasibility of the new contact alloys in solving critical contact performance problems. It is felt that the problems associated with weld flash and weld security can be resolved at a later date by the use of controlled rhodium deposition techniques.

Contact resistance during the final cleaning operation was within the norm, and no major problems were encountered during assembly. There was no detectable difference between lot 17 which had rhodium plating and lots 19, 21, and 23 which had gold over rhodium. The contact resistance stability was identical to the standard gold plated contact system.

Lot 19 consisted of a modified motor assembly developed to reduce the problem associated with a marginal gold-germanium brazing operation. These relays utilized a higher temperature, AgCuSn braze alloy with greater strength. The results were promising from the standpoint of hermeticity; however, the adjustment of the motor assembly became critical, and, as a result, the modules' operate voltage exceeded the specifications. This process variation did not have an effect directly on the contact performance, and there was no measurable difference between lot 19 and the remaining lots utilizing the rhodium plated contacts.

Contact Performance Tests

The test program used to evaluate the contact performance of the three groups of experimental contact material relays was identical to that used in the first phase of the study. Measurements of the electrical characteristics before and after the life tests were performed on automatic test equipment. The data was punched on IBM cards for subsequent computer processing. Measurements of hermetic leakage were made on a mass spectrometer leak detector after the life tests.

Contact performance tests consisted of low level life (300 microamperes, 30 millivolts, 10 ohm criterion), intermediate load life (100-milliamperes, resistive, 28 VDC, 100-milliohms criterion), and power life tests (2-ampere, resistive, 28 VDC, weld and 3-ohm criteria). All tests were run for 100,000 operations or malfunction, whichever was less. In the majority of cases, the 100-milliampere life tests were performed using continuous monitoring recorder techniques which measured the contact resistance during each operation. The detailed procedures are outlined in the first section of this report.

Monolithic Contact Relay Test Results.--A total of 78 Super J relays were tested using the monolithic type contact system. Lot 24, alloy 1A, consisted of 40 relays and lot 25, alloy 1B consisted of 38 relays. The relays were approximately equally divided among low level, intermediate, and power load life tests.

The most significant electrical parameter measured on the automatic test equipment is the contact resistance, of which there were eleven measurements made per contact on each relay using a 100 milliampere, 6 VDC contact load. The remaining parameters: coil resistance, operate-release voltage and time, and contact bounce are indicators of the overall relay adjustment and were used for lot uniformity comparisons.

Of the 3.432 measurements of initial contact resistance, only one reading exceeded 30-milliohms; it was 38 milliohms. Both lots 24 and 25 had identical distributions with means of 22-milliohms and a combined range of 17 to 28-milliohms. Contact resistance variation between readings on the same contact, an indication of contact resistance stability, was typically less than 2 milliohms.

After the 100,000 operation life tests, there was a significant increase in the contact resistance distributions. Lot 24 (Alloy 1A) became highly skewed to the right with ten of the forty relays exceeding the 30-milliohms criterion. These were all normally open contact failures ranging between 35 and 70 milliohms. The remaining relays ranged between 18 and 28 milliohms with a mean of 23-milliohms. There was a loss of the initial contact resistance stability on both lots of relays.

Table XX summarizes the overall contact life test results on both lots of monolithic contact relays using the same criteria used on the standard gold plated silver alloy contact relays.

The low level life test results, for the first 50,000 operations at 125°C, showed two units missed (total of three misses). The initial contact resistance for lot 24 and 25 at 125°C ranged between 19 and 26 milliohms. After the 50,000 operations at 125°C, the maximum contact resistance was 34-milliohms, and the balance of the units ranged between 20 and 26 milliohms, excluding the maximum value. The -65°C contact resistance measurements performed after the thermal shock from 125°C revealed two failures. One unit exhibited an open contact and the other showed a 39-milliohms contact resistance.

TABLE XX

SUMMARY OF LIFE TEST RESULTS ON MONOLITHIC CONTACT RELAYS

	Lot 24 Alloy 1A	Lot 25 Alloy 1B
LOW LEVEL LIFE TEST		
Miss Failures in 10^5 operations	2/13	2/14
Miss Failures at 125°C	1/2	1/2
Miss Failures at -65°C	2/2	2/2
CR 30-milliohms at 125/25°C	1/13	0/14
CR 30-milliohms at -65°C	8/13	2/14
INTERMEDIATE LOAD LIFE (100ma)		
CR 100-milliohms	2/13	1/10
POWER LOAD LIFE (2-amperes)		
Catastrophic Failure Mode	4/14	3/14
Parametric Failure Mode	0/14	2/14

Notation: Failure/sample size; CR Contact Resistance

The 50,000 operations at -65°C revealed two failures from each lot. Two of these relays had previously missed at 125°C, and one of the units was associated with the relay that exhibited an open contact during the thermal shock test. The post contact resistance measurements at -65°C indicated a large increase in the contact resistance when compared to the initial -65°C measurements.

As indicated in Table XX, lot 24 had a significant number of -65°C failures when compared to lot 25. The maximum contact resistance on both lots at room temperature after the -65°C contact resistance tests was 31-milliohms. This radical change in contact resistance as a function of temperature is associated with the "icing" phenomenon previously discussed and is an indication of excessive water vapor inside the modules. For some reason, lot 24 exhibited a higher percentage of failures associated with water vapor than lot 25. It is significant to note that there was no indication of cold welding on either of these two alloys.

The intermediate load (100-milliampere) life tests were conducted at 125°C for 100,000 operations using a continuous monitoring recorder. Only 8 out of the 23 relays tested did not exhibit a significant change in resistance; however, only three units exceeded the 100-milliohm criterion. In general, the contact resistance would vary up to 50-milliohms for some fraction of the 100,000 operations and then return to the norm (below

30-milliohms). There was no indication of cold welding or a significant trend of contacts that favored the normally open or normally closed contact position. Lot 24 exhibited a slightly higher incidence of contact resistance variation than lot 25.

The power life tests (2-ampere) results were consistent between both lots. The major failure mode was welding of the normally open contacts. Table XXI summarizes the failures encountered.

TABLE XXI

POWER LOAD (2-AMPERE) LIFE TEST FAILURE MODES

First Miss	Total Misses	Failure	Lot	Mode
70	5	1,500	25	excessive misses
3,200	1	3,200	25	normally open 1 weld
4,200	1	4,200	24	normally open 5 weld
40,000	1	40,000	24	normally open 1 weld
41,300	1	41,300	24	bridged contact 2
54,200	1	---	25	one miss in 100,000 oper.
74,400	1	74,400	24	normally open 1 weld
79,700	1	79,700	25	bridged contact 2
80,700	1	80,700	25	normally open 1 weld

As indicated in the table, three of the failures were of the infant type, three occurred at the mid-point in life, and the remaining three were towards the end of life. The fact that 19 out of the 28 relays tested went through the life test without a miss is an indication of the feasibility of these alloys. These failures were of a temporary nature, and the final electrical characteristics after life did not correlate to the above failures. However, some of the units exhibited high contact resistance after life but did not exceed the 100-milliohm limits.

Rhodium Plated Contact Relay Test Results.--A total of 90 Super J relays using rhodium plated fixed contacts were tested in this phase of the study. These relays were manufactured and tested in four lots totaling 31 groups. Since the use of rhodium plating was proposed as a possible solution to the cold welding problems encountered during low level life testing, a total of 44 units were subjected to the low level life tests, and the remaining units were equally divided between the intermediate and power load life tests. The relays were randomly selected from each group and were manufactured over a time period covering over four months.

The initial contact resistance measurements as well as those obtained after life testing indicated an unusual degree of uniformity and stability. Of the 7,920 measurements, only two units exceeded 30 milliohms. These units had resistances of 42 and 38 milliohms after intermediate load life tests. The overall range of contact resistance, excluding the above units, was 18 to 28 milliohms with an average of 23 milliohms. The variation between readings on the same contact typically was less than 2 milliohms. There was no significant difference between the initial contact resistance and that obtained after the 100,000 operation life tests.

The four lots of relays exhibited similar performance characteristics. The only exception was lot 23 which was manufactured during the latter part of the study. This lot had a higher incidence of power load life misses, the cause of which is unknown. No significant difference was found between the relays that had a gold plate over the rhodium and those without this plating. Table XXII is a summary of the overall contact performance of all four lots of rhodium plated contact relays.

TABLE XXII

SUMMARY OF LIFE TEST RESULTS ON RHODIUM PLATED CONTACT RELAYS

	Lots 17, 19, 21 & 23 31 Groups, 90 Relays
LOW LEVEL LIFE TEST	
Miss Failures in 10^5 operations	5/44
Miss Failures at 125°C	4/5
Miss Failures at -65°C	3/5
CR 30 milliohms at 125/25°C	3/44
CR 30 milliohms at -65°C	7/44
INTERMEDIATE LOAD LIFE (100-ma)	
CR 100 milliohms	1/20
POWER LOAD LIFE (2 amperes)	
Catastrophic failure mode	0/26
Parametric failure mode	9/26

Notation: Failure/sample size; CR Contact Resistance

The low level life test results for the first 50,000 operations at 125°C showed four failures. All of these relays were from lots 21 and 23. There was no indication of contact resistance variations or cold welding associated with these failures. It is interesting to note that prior to these failures, a series of 33 relays representing 21 different groups had been successfully tested. It appears that these four failures were process dependent and not a function of the contact materials. The contact resistance measurements taken before and after the 50,000 operations at 125°C ranged between 24 and 34 milliohms with an average of 27 milliohms. There was no change in the contact resistance distribution as a result of the 50,000 operations. The -65°C contact resistance measurements performed after the thermal shock from 125°C showed seven relays with high or open contact resistance due to the "icing" phenomenon. Two of these relays also indicated low level misses which correlated to the initially high contact resistance. Excluding these abnormalities, the contact resistance measurements at -65°C, before and after the 50,000 low level life test, ranged between 15 and 24 with an average of 18 milliohms. There was no indication of temperature dependent contact resistance when the post-measurements made at room temperature were compared to the final -65°C readings. A very high degree of stability was noted on these relays. There was no indication of cold welding during these tests and the majority of failures were associated with the relays' atmosphere rather than the rhodium plated contact material.

The intermediate load (100-ma) life tests were conducted for 100,000 operations at 125°C. Of the 20 units tested from 14 different groups, only one unit exceeded the 100 milliohm criterion. This unit was from lot 23 and is an indication of a defective atmosphere due to either the hermetic seals or the vacuum outgassing procedure. In general, the maximum contact resistance change in 100,000 operations did not exceed 20 milliohms and usually was below 5 milliohms.

The power load (2-ampere) life tests were also quite consistent with the exception of relays in lot 23. A total of 2.6 million relay operations were accumulated without catastrophic failure. Of the nine units that exhibited parametric failures (misses), six were associated with lot 23. Table XXIII is a summary of these parametric failure points. The remaining failures had only one miss in 100,000 operations and these were randomly distributed throughout the life test.

No conclusions can be drawn from this data other than that lot 23, when compared to the other three lots of rhodium plated contacts, is not representative of the contact performance that can be expected from the rhodium contact material.

Relay Analysis and Correlation

<u>Monolithic Contact Relays</u>.--It was necessary during this stage of the program to separate the variables associated with the contact materials and those independent of the materials. For example, as a result of the variation in the hermeticity of the contact modules, some of the low level and intermediate load

TABLE XXIII

POWER LOAD (2 AMPERE) LIFE TEST PARAMETRIC FAILURE DISTRIBUTION

First Miss	Total Misses	Total Operations	Lot	Type Miss
4,300	9	100,000	23	normally open
6,000	1	100,000	19	normally open
15,600	7	100,000	23	normally open
18,600	2	100,000	23	normally open & closed
26,600	1	100,000	23	normally closed
72,200	1	100,000	21	normally open
84,100	3	100,000	23	normally open
86,900	1	100,000	21	normally open & closed
94,200	1	100,000	23	normally open & closed

contact resistance failures were associated with the atmosphere rather than with the contact material. The fact that the initial contact resistance distribution on both lots of relays was low and stable after the vacuum outgassing, backfilling, and final sealing operation is an indication of the inherent stability of the material if the atmosphere inside the contact material can be maintained. This is the main reason for the difference in contact performance between lots 24 and 25.

The results reported in the last section indicated some trends towards favoring alloy 1B (Ag-17Pd-5Cu) over alloy 1A (Ag-17Pd-8Cu) with respect to contact resistance stability. However, if the failures associated with the atmosphere variation between lots are removed and the test data is reexamined, there is no significant differenece between the performance of lots 24 and 25. These findings were confirmed by a second chemical analysis of the two contact alloys by an independent laboratory. The findings are reported in Table XXIV.

TABLE XXIV

CHEMICAL ANALYSIS OF ALLOYS 1A AND 1B

Actual Composition (weight/%)	Alloy 1A	Alloy 1B
Silver	74.5	73.0
Palladium	19.6	20.5
Copper	6.2	6.7

Therefore, as was suspected, there was little difference between the two final test alloys. One might consider for the final alloy developed in the study a composition of Ag-20Pd-6.5Cu.

The contact surfaces of a unit which underwent normally open welding after 74,400 operations was examined. There was evidence of high heat concentration and melting at the contact area. The presence of oxide discoloration suggested a poor hermetic seal. The fact that a high percentage of the units did not weld in 100,000 operations at 2 amperes indicated that this was not an intrinsic problem. Several possible causes for this type of failure are: localized segregation or lamination in the contact strip; poor precleaning or film formation during operation due to a faulty hermetic seal; improper make-break adjustment; and poor thermal transfer due to a marginal terminal pin to contact welds. The possibility remains, however, that with a more extended life test, this failure mode may become more prevalent. The resolution of this point would require, therefore, an additional test program performed on more than one melt of the alloy.

It is concluded that the major causes of contact resistance variations were associated with the hermetic seal and the loss of atmosphere control in the module. There was no indication of cold welding on units which exhibited low and stable contact resistance throughout life, which bears out the conclusion that this material is not prone to cold weld as is the case with the gold plated silver alloy contacts.

The analysis of the hermetic history indicated some degradation of the seals as a result of the test program. No additional investigation was made on the contact modules with respect to the correlation of leakage or atmosphere to performance due to the rather extensive work performed in the first section of this study.

Rhodium Plated Contact Relays.--This phase of the study was directed towards determining why the rhodium plated contact performance was so consistently superior to that of the gold plated silver alloy contact relays manufactured for the Process and Contamination phase of the study. It is important, for purposes of comparison, to remember that the rhodium plated contact relays were manufactured concurrently with the gold plated silver alloy contact relays so as to eliminate the problem with unknown process variations.

Unfortunately, lot 23, the maverick of this group, was manufactured during the last part of the study as an independent group, and there were no controlled comparison standards available. In reviewing the manufacturing records, the only tangible evidence found to support the fact that lot 23 was not representative and, therefore, should be eliminated from this comparison was associated with relay adjusting problems. It is possible that a marginal group of motors from the standpoint of strength and hermeticity was used in assemblying these relays. The net result could have been a loss of adjustment stability and erratic contact forces that could have directly affected the contact performance particularly in the power load life tests. For the present, this lot of relays has been eliminated from this comparison due to its lack of lot uniformity.

Since the prime purpose of the rhodium plated contacts was to eliminate the cold welding and adhesion of the silver alloy substrate material, a detailed analysis of the wear was performed. As expected, the rhodium plate was eroded and transferred during the power load life tests as a result of the 2-ampere, 28 volt arcing. This is not unusual since the 2.5 to 5.0 microns of rhodium is not sufficient to withstand this amount of arcing for 100,000 operations without deterioration. Transfer of the gold, silver, and rhodium, a complex phenomenon, was observed on the contacts examined. The conditions observed were estimated as normal for the type of load conditions, and no further evaluation was performed.

Relays that were subjected to the 100,000 operation low level life test were carefully analyzed. Correlation was obtained between the units that failed the low temperature test and the atmosphere. As previously reported, the hermetic seal associated with the core braze and coil feedthru was marginal. By relating the leakage after life test and the initial leakage, it was possible to summarize that some exchange of the atmosphere had occurred. Since these relays had been operated in a high level of water vapor, they would not be prone to cold weld due to monolayer adsorption of water. On relays that had a higher level of water vapor, estimated to be of the order of 1,000 ppm or higher, there was very little discernible wear associated with the 100,000 operations. These relays were not considered as representative of rhodium contact performance under worst case conditions (i.e. low water vapor, less than 100 ppm).

The most significant findings were found on the relays that had successfully completed the low level life test, did not show any indication of atmosphere discrepancies as evidenced by the low temperature tests, and had leak rates of less than $5(10^{-9})$ atm cc/sec before and after the life tests. The contact surfaces of these relays showed at least an order of magnitude less wear and evidence of adhesion when compared to the gold plated contacts of the standard relays. The wear characteristic was one of material smearing on the surface of the rhodium with some evidence of slight adhesion of the gold plate from the mating contact. Figures 21 and 22 are a comparison of gold plated silver alloy contacts and a typical rhodium plated contact operated under very dry conditions. This damage was strictly due to mechanical effects, since the contacts operated with a low level signal, and minimal cable discharge effects. The silver alloy is clearly exposed on the gold plated contacts which accounts for the cold welding, while the rhodium plated contact surface has not been markedly damaged. In no case was the silver alloy exposed in less than 100,000 operations.

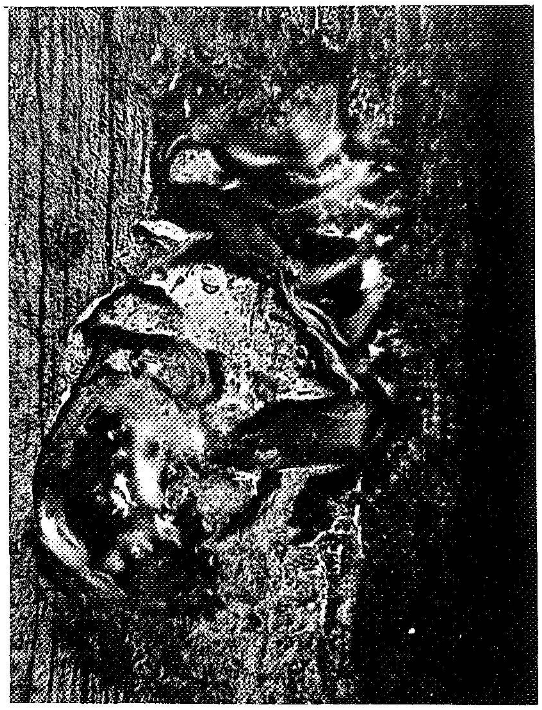


FIGURE 21
150X, Au Plated, Ag Alloy
Movable Contact, "Dry"
Atmosphere, After 10,000
Cycles Low Level Life Test
(Lot 16)

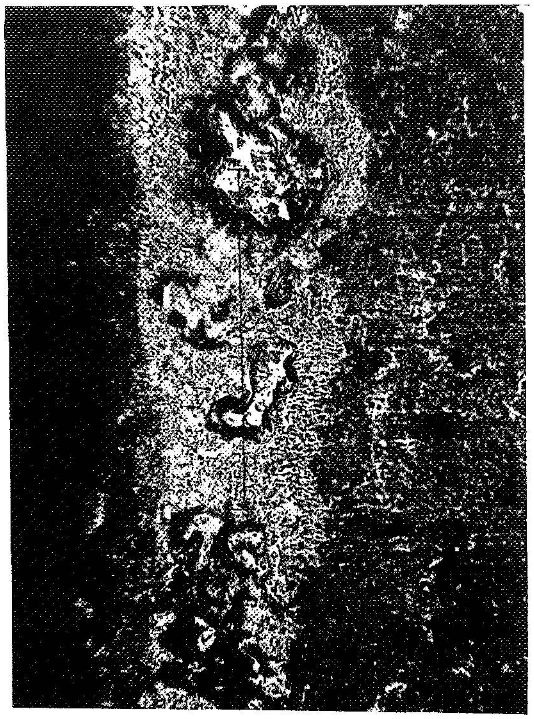


FIGURE 22
150X Rh Plated Contact, "Dry"
Atmosphere, After 100,000
Cycles Low Level Life(Lot 19)

Figures 23 and 24 are photomicrographs of a normally open contact pair showing both the rhodium plated fixed contact and the mating gold plated movable contact. As can be seen, there is a slight amount of materials transfer, but there is no penetration into the silver alloy. The rhodium plate remained in tact.

Some of the other units that were examined indicated a slight amount of polymer formation, but of such a small magnitude that it did not affect the contact resistance. This polymer formation is an indication of trace amounts of organic materials within the contact module. It is suspected that with rhodium plated contacts it would be possible to lengthen the vacuum outgassing cycle and, thereby, eliminate the polymer by upgrading the atmosphere.

It was concluded that the rhodium plated contact material successfully eliminated the cold welding problem due to the increased hardness and elasticity. The 2.5 to 5.0 micron thick rhodium plate was sufficiently strong to resist deformation over the soft silver alloy substrate that the rhodium was not fractured with contact forces up to 22-grams. There was not a significant difference between the gold overplate on the rhodium and the straight rhodium under these conditions. The discrepancies noted in contact performance were associated with an abnormal lot (23) and variation in the contact modules' atmosphere which is related to the leakage problem previously discussed.

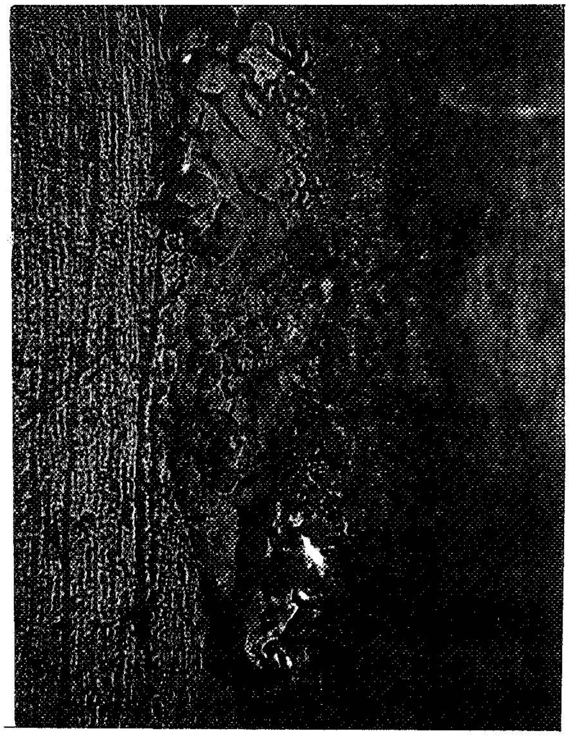


FIGURE 23
Au Plated, Ag Alloy
Movable Contact

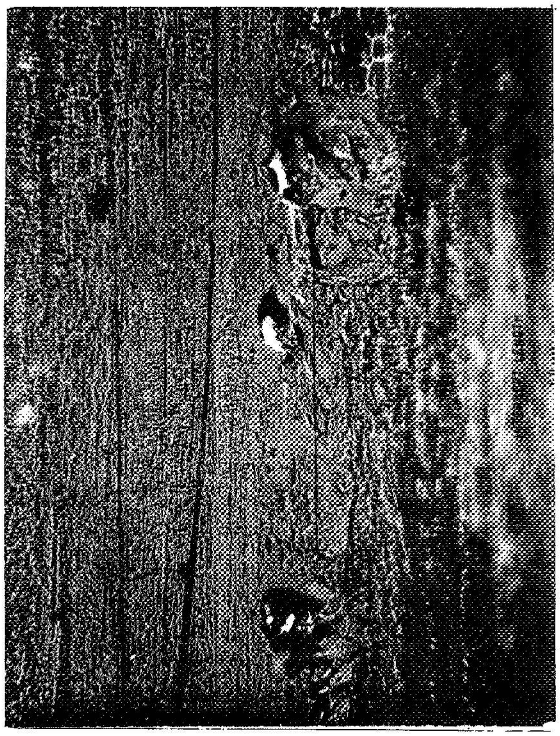


FIGURE 24
Rh Plated
Fixed Contact

150X, Typical Contact Pair After 100,000 Cycles Low Level Life, "Dry" Atmosphere, (Lot 19)

CONCLUSIONS AND RECOMMENDATIONS

Critical manufacturing processes, such as vacuum outgassing and cleaning, were evaluated and control techniques were developed to monitor these processes. Correlation among vacuum outgassing parameters, leakage, atmosphere, wear, and contact performance was found for a typical gold plated, silver alloy contact material used in "sealed switching module" relays.

It was concluded that the limiting factor in obtaining reliable contact performance under "dry" conditions was the contact material. Leakage, as a result of the manufacturing processes, causes the majority of low temperature failures due to an increase in the water vapor content inside the relays.

Cold welding of the contacts after 30,000 operations was associated with wear through the gold plate and adhesion of the silver alloy contact material. This basic material failure mechanism was eliminated by the use of rhodium plated contacts. The intrinsic performance of the switching sealed contact module was not demonstrated due to the above factors. The elimination of the cold welding by the use of rhodium greatly improved the contact performance.

It is recommended that the overall hermetic aspects of these types of components be reviewed and techniques, other than sealants, be developed to radically improve manufacturing yields and overall hermetic reliability. It is felt that this area is one of the major limiting factors in this type of component.

Monolithic Contact Materials.--A ternary, age hardenable, alloy of silver-20% palladium-6.5% copper was developed for application as a monolithic contact spring material. The alloy has a tensile strength, after age hardening, in excess of 100,000 psi; is resistant to stress relaxation at 250°C under applied stresses up to 40,000 psi; and has excellent ductility with elongations in excess of 20%. The electrical resistivity is acceptable, and the contact resistance is low and stable in an inert atmosphere.

The application of this monolithic material was demonstrated in Super J type switching modules with promising results. There was no indication of cold welding or contact weld failures up to the intermediate load region; however, there were welding failures experienced while switching 2-amperes. The latter is not believed to be an intrinsic material problem at this time.

It is recommended that additional melts be made of this alloy and a more extensive program be developed to further demonstrate and finalize this promising contact alloy since the application to miniature components in many fields, including sliding contacts, could be quite beneficial.

Rhodium Plated Contacts.--Although the use of rhodium electrodeposits as a hard-wearing electrical contact material is well known, the feasibility that was demonstrated of using rhodium over a soft silver substrate in extremely "dry" atmospheres has not been previously reported. The use of rhodium contact systems in components without organic contaminants eliminates the classical polymer formation and activation phenomena as was found to be generally the case with sealed switching modules.

Rhodium plating offers the most promising solution to the immediate problems of cold welding in Super J type sealed switching modules. The use of this material allows an additional margin of safety that can be built into the vacuum outgassing processes by extending either the time or increasing the temperature. The use of a thin, less than 1/2 micron, gold overplate is recommended to improve the lubricity and resistance stability on theoretical grounds since no discernible difference between these two lots could be found.

The use of rhodium plated contact pairs rather than the rhodium-gold mixed contact system is suggested for extending the operational life of the contact surfaces beyond 100,000 cycles. Improvement in the atmosphere stability is a necessity for reliable contact performance as has been demonstrated on all lots tested, and it is recommended that this material combination be used to evaluate upgraded vacuum outgassing cycles.

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APPENDIX A

NEW TECHNOLOGY

AN AGE HARDENABLE ELECTRICAL CONTACT SPRING MATERIAL

(Reference: Contact Material Section of This Report)

A ternary, age hardenable, alloy of silver-20%palladium-6.5%copper was developed for application as a monolithic contact spring material. The alloy has a tensile strength after age hardening, in excess of 100,000 psi, is resistant to stress relaxation at 250°C under applied stresses up to 40,000 psi, and has excellent ductility with elongations in excess of 20%. The electrical resistivity is acceptable, and the contact resistance is low and stable in an inert atmosphere. The application of this alloy to miniature components in many fields, including sliding contacts, could be quite beneficial.