THE GROWTH OF METAL WHISKERS ON ELECTRICAL COMPONENTS

S. M. Arnold
Bell Telephone Laboratories, Inc.
Murray Hill, New Jersey

Introduction

Bell Telephone Laboratories has had an active program devoted to studies of the nature of metal whisker growth since a number of transmission troubles were traced directly to the presence of conducting filaments on the surfaces of some closely spaced parts in telephone equipment about ten years ago. Prior to actual failure, characterized by low impedance to ground in equipment which had been operating satisfactorily for many months, there had been no indication of equipment degradation. Failure of the hermetically sealed units evidently had occurred because of something not present at the time of installation and was not a result of a progressive component deterioration such as might be associated with corrosion or absorption of moisture. Identification of the part the filaments played in the equipment failures and the subsequent findings that the filaments were metallic and actually required a period of time to develop, indicated that troubles of this kind would not be confined to a particular type of apparatus. Such failures might be expected at some indefinite time in any equipment in which specific metals, small spacings, low voltages and critical circuits were involved.

These indications have been confirmed, and numerous failures since have been traced to the presence of metallic whiskers. Where high voltages exist destruction of any bridging whiskers automatically occurs but their importance must certainly increase as low voltage circuitry and microscopic spacings become adopted ever more widely.

This report has been written to illustrate the variety of equipment types in which metal whiskers have been found, to describe a number of the actual service failures traced to the presence of these whiskers and to suggest possible methods of preventing such failures.

Components Associated with Whisker Growth

Of interest because it was the first part of the telephone plant in which growths of conducting filaments are known to have caused electrical failure, is the channel frequency filter shown in Fig. 1. In this unit, essential for the simultaneous transmission of a number of conversations over a multichannel telephone line, whiskers developed on zinc-plated brackets and bridged across to nearby air capacitors, as shown in Fig. 2. Approximately one year was required from

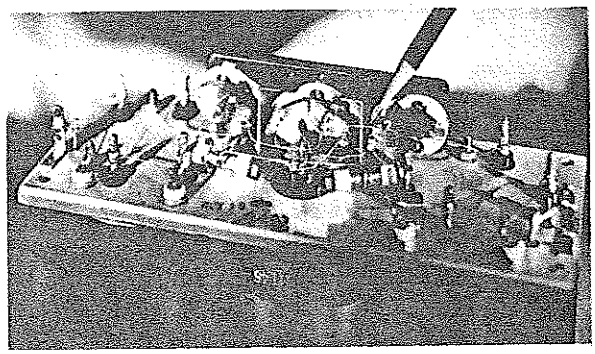

Fig. 1. Channel frequency filter. Pencil indicates spacing bridged by whiskers.

Fig. 2. Zinc whiskers responsible for low impedance in channel filter. Spacing bridged approximately 3/16 in.

the time of assembly until a low impedance condition developed as a result of whiskers spanning this 3/16 in. spacing.

Shortly after the troubles in the channel filters had been traced to the presence of such filaments, a failure of a sensitive potentiometer also was identified with metal whisker growth. Here the whiskers had not developed on the potentiometer itself, however, but on the inside of the potentiometer enclosure. The enclosure was made of tin-plated steel, and whiskers had grown on the internal tin coating. Some of the whiskers had become dislodged and fallen across several turns of the potentiometer winding.

What may have been a somewhat similar situation arose with regard to a number of carbon resistors. This type of resistor is made by depositing a film of pyrolytically formed carbon onto a ceramic core. The completed resistor in effect consists of a core coated with a spiral ribbon of carbon, with adjacent turns separated from each other by a narrow spiral path free of carbon. Positive contact is obtained at the ends of the core by means of silver paste and brass ferrules. The ferrules themselves are tin plated to insure good contact with the mounting clips. Whiskers were found on a number of the ferrules. Nonpersistent troubles had been experienced with some of the resistors, and it was believed that whiskers from the ferrules had become detached and lodged across the gap separating adjacent turns of the carbon film.

A copper oxide rectifier destined for military use failed in preservice trials because of the growth of metal whiskers. Figure 3 is an enlarged view of a portion of the rectifier. * The whiskers can be seen bridging between the tin coated terminals, short circuiting the unit. Because it had been enclosed, the actual trouble was found only after the unit had been dismantled, an operation not always possible or desirable under field conditions.

In Fig. 4 is shown a part of a protector mounting which failed because of whisker growth. In the assembly of this particular mounting, a clamping screw passes through a cylindrical bushing and forces the end of the bushing into close contact with a plated terminal lug.

This is an example of a situation in which the likelihood of trouble due to whiskers is enhanced by assembly requirements. It is believed that whisker growth is a result of stress. Further, it has been shown that pressure accelerates the growth of whiskers. [1] In the pileup in question, compression stresses are exerted by the clamping screws and a high pressure is developed at the edge of the bushing where it bears against the terminal face. There is sufficient space at the side of the bushing for whiskers developing in the highly stressed area to pass through to the adjacent terminal and establish a low impedance path. In Fig. 4 can be seen a few of the relatively long whiskers which developed at the edge of the high pressure area immediately adjacent to the rim of the bushing. Also, there are present a few of the shorter whiskers characteristic of those observed on other parts of the surface outside of the pressure area.

The terminal strip is a frequently used component in a wide variety of equipment. It is available in many forms, but often consists essentially of a series of closely spaced metal fingers or lugs protruding from a strip of insulating material. A hot-dipped or electroplated coating of tin or tin-lead is usually applied to insure ease in making soldered joints. In Fig. 5 an enlarged view of a portion of a unit with tin-plated terminals makes clear the reason occasional failures are encountered.

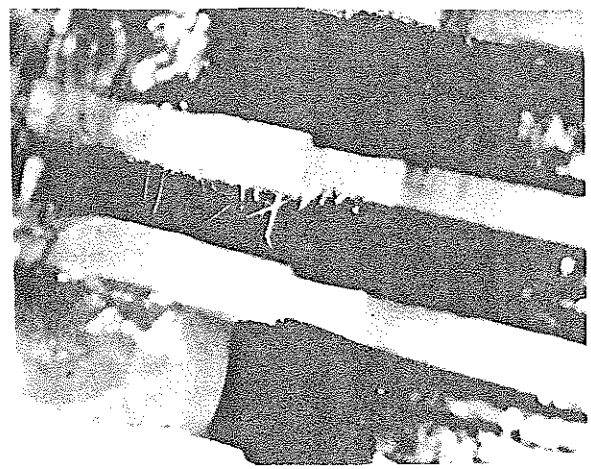

Fig. 3. Tin whiskers growth in trouble area of a copper oxide rectifier (18X).

* The original magnifications indicated in the figure captions have been subjected to various reductions in making the halftone illustrations. - The Editor

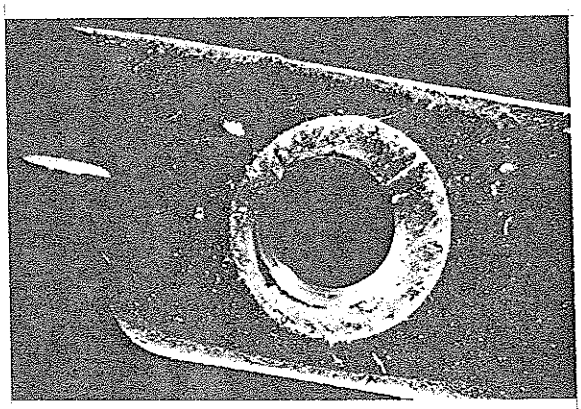

Fig. 4. Protector mounting terminal. Tin whiskers in high pressure area (15X).

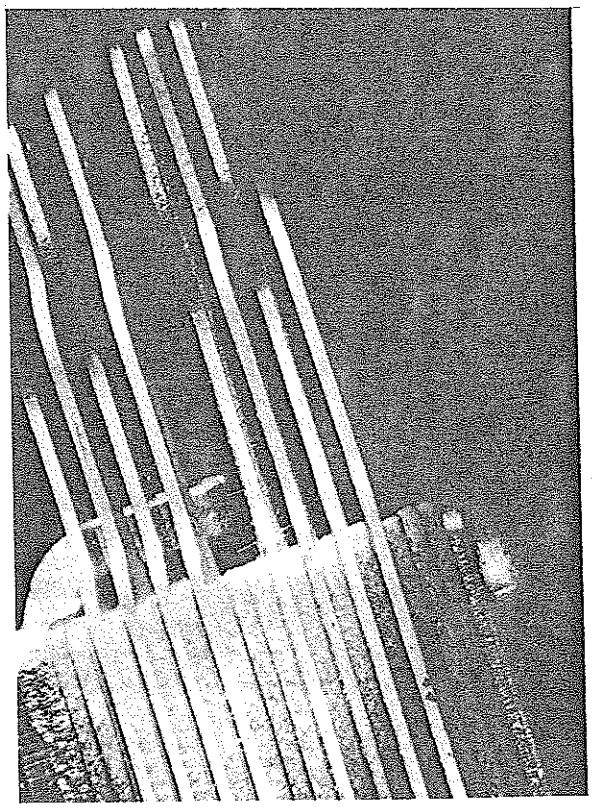

Fig. 5. Tin whiskers on individual members of terminal strip (4X).

There have been some instances where metal whiskers developed on relay members. The magnetic iron parts require a surface finish as protection against corrosion. Electroplated nickel or nickel plus chromium may be used, but frequently zinc or cadmium is applied. The contact springs often are tin-coated at the clamped ends to facilitate soldering, and the pileup pressure is applied by means of screws bearing on compression plates which may be coated with tin, zinc or cadmium. Either zinc or cadmium may be applied to the armature return spring. In Fig. 6 is shown a relay contact spring and some of the whiskers responsible for a grounded circuit. Figure 7 shows how whiskers grew on one of the compression plates of a relay and came into contact with an adjacent spring. This situation is similar to that described in the discussion of the short-circuited protector mounting where stress accelerated whisker growth.

Another type of failure attributed to whisker growth took place in a relay operating in a circuit handling some 200 volts. A persistent arc caused considerable damage to the relay. Examination disclosed the presence of numerous whiskers on contact supports. It is believed that whiskers had bridged between closely spaced parts to initiate an arc and, once initiated, the arc had been maintained by the standing voltage until protection devices operated to cut off current flow.

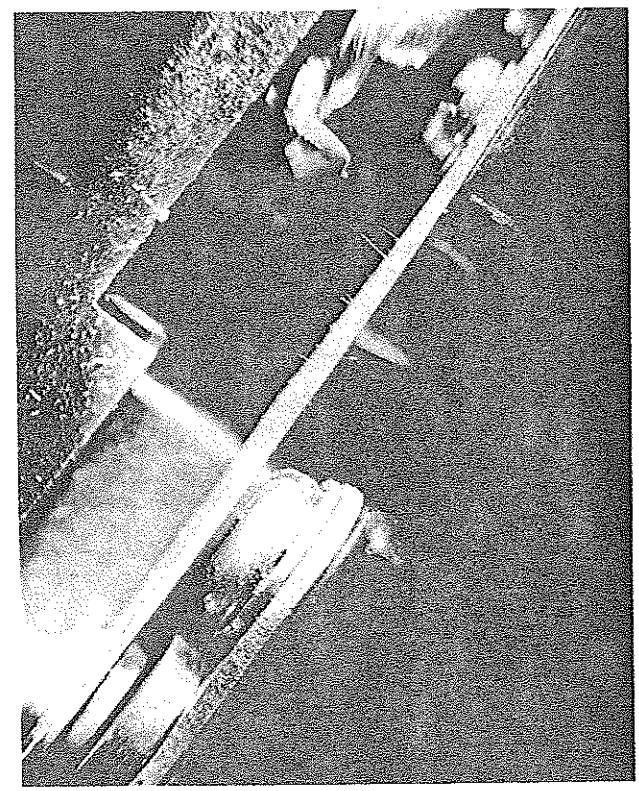

Fig. 6. Whiskers on tin-plated relay contact spring (12X).

A relay armature return spring, electroplated with cadmium, is shown in Figs. 8 and 9. An appreciable growth of whiskers, some of them quite long, has taken place. Here, of course, they will cause no trouble as long as none becomes lodged at some vulnerable area.

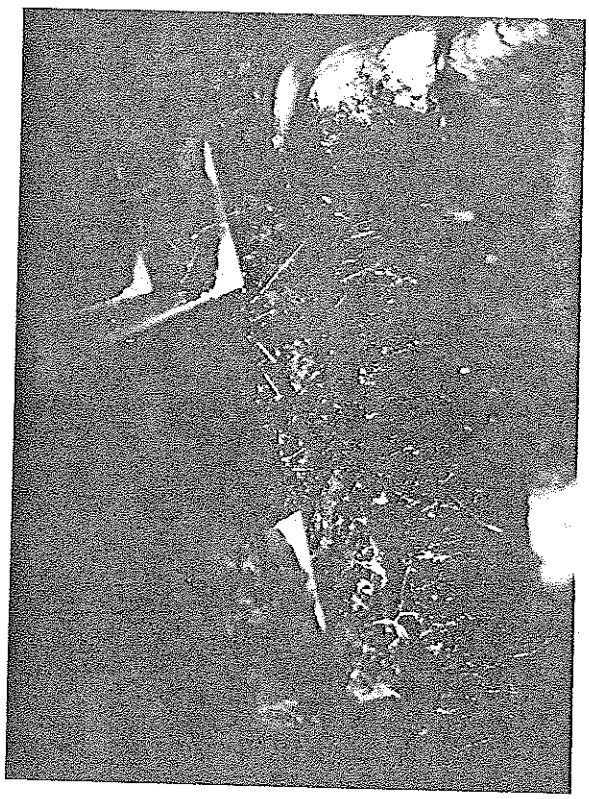

Fig. 7. Tin whiskers along edge of high-pressure area spring pile-up area of relay (15X).

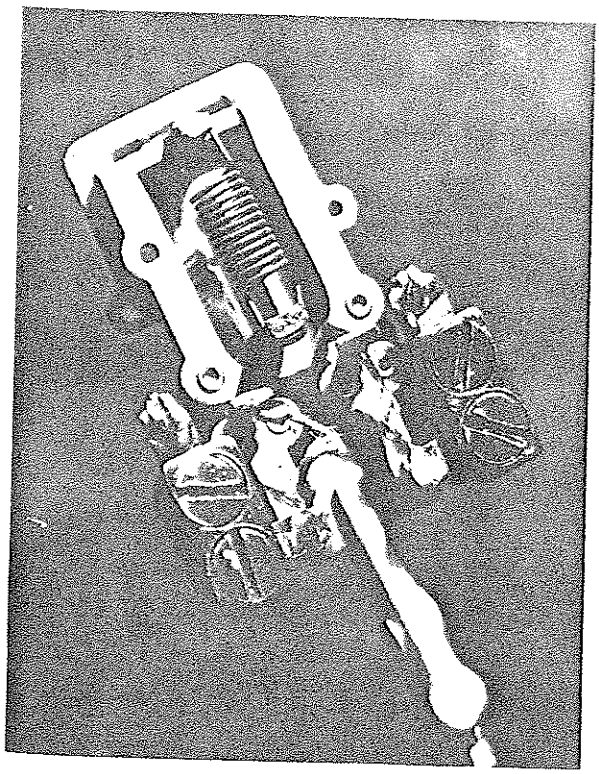

Fig. 8. Small relay (1.5X).

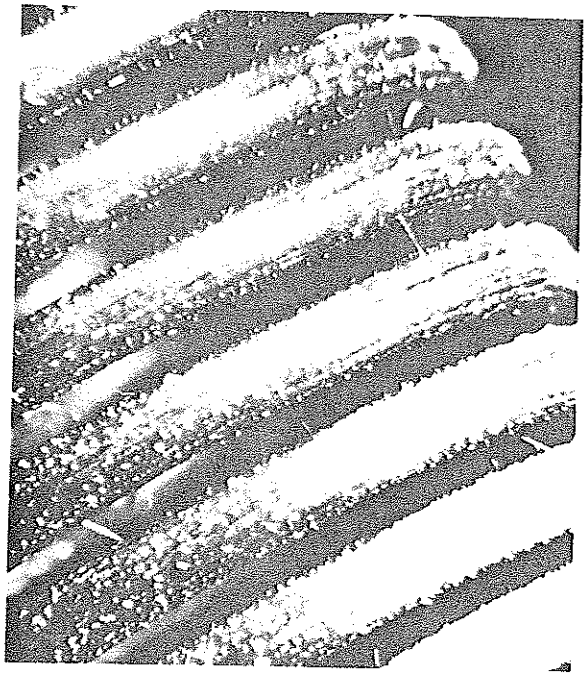

Fig. 9. Whiskers on cadmium plated armature return spring of relay shown in previous figure (30X).

Another widely used element is the variable air capacitor. This too has at times been the site of whisker trouble and was referred to as far back as 1946.[2] While aluminum frequently is specified in the

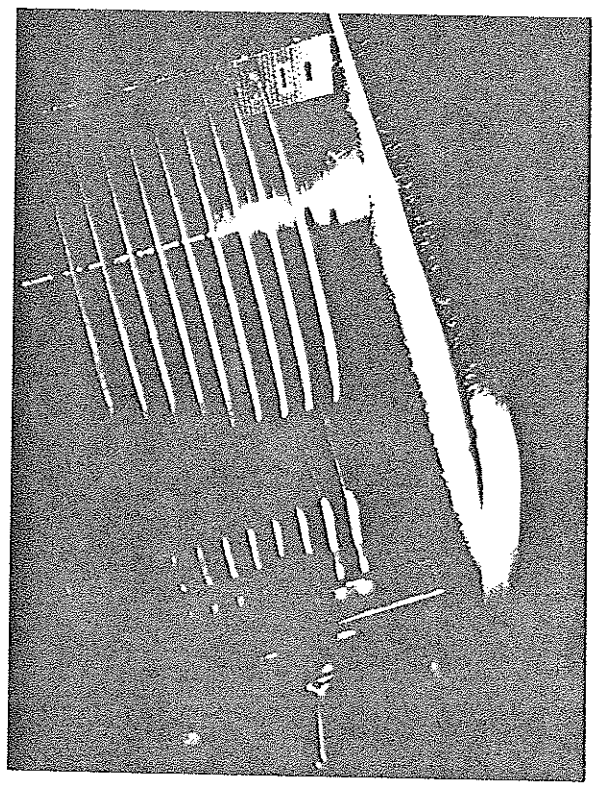

Fig. 10. Heavy growth of whiskers on end plate of variable air capacitor (3X).

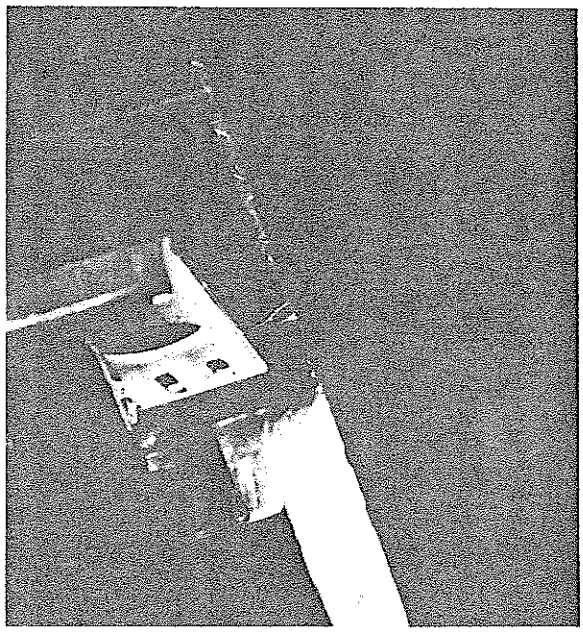

Fig. 11. Whiskers short-circuiting capacitor shown in previous figure (6X).

fabrication of these capacitors, both brass and steel are used and may be left unfinished or coated with cadmium or zinc. A portion of one such variable capacitor with a fuzz of whiskers on the plated end piece is shown in Fig. 10. In Fig. 11 can be seen the whisker growths which led to failure when contact was made with an adjacent plate.

Whiskers have also been observed in metallized capacitor paper. The capacitors are made by winding many turns of two sheets of the metallized paper to produce a closely wrapped spiral sandwich of alternate layers of paper and metal. Electrical contact is obtained at the ends of the two metal films by means of projecting tabs soldered to flexible leads or to terminal posts. Samples of capacitor papers coated with zinc or cadmium have been examined, and on a number of them metal whiskers have been found.

While there have been no reports of failures which could be identified with whisker growth in this type of unit, the question of the possibility of such failure has been raised frequently enough to warrant a brief comment. There is no evidence that growing whiskers will penetrate the interleaving paper used in capacitors. Actually, whiskers have been grown in contact with such paper, but they were deflected without penetration. Only if the metal film extended to the paper edge so that projecting whiskers could make contact with the can cover or leads might there be a possible, although unlikely, trouble condition.

Because the function of a chassis is to serve purely as a structural member, it may be overlooked complely when reliability is under consideration. However, many chassis are fabricated from steel electroplated with cadmium or zinc which have a tendency to develop whiskers. In a cadmium-plated chassis examined some two years after purchase, whiskers were found to exist over the entire surface. Furthermore, this was not an isolated case. Other chassis have been seen with comparable growths. The presence of whiskers on a chassis would be usually of academic interest but there is the possibility that whiskers may be detached and find a resting place in a critical circuit area. Furthermore, should a conducting member of a circuit inadvertently be located or displaced so that it is only a short distance from the chassis, contact could easily be made in an area of dense whisker growth.

Also of interest is the component can cover used to minimize the deposition of dust, reduce air flow and gaseous contamination and to serve as electrical or magnetic shielding. Although a cover may not be an integral part of the electrical circuit, it may be responsible for troubles connected with metal whiskers. Many can covers are electro-finished with corrosion-protecting coatings of zinc or cadmium or may be tin-coated because of solderability requirements. Growths of whiskers on such surfaces are not uncommon and, as pointed out in the discussion of the failure of a potentiometer, may be responsible for the malfunctioning of a component if dislodged whiskers get to the wrong places. Whisker growths have been found on the internal surfaces of cans used as capacitor and relay covers, transistor enclosures and small instrument housings. Cadmium whiskers in thermostat enclosures have been referred to in the literature. (3)

Of related interest are several units that were enclosed in plated brass or steel cans but where a different situation developed. Here troubles arose because of whisker growth not in the inside, but on the outside surfaces of the cans, either on a lip or a rolled edge separated only a short distance from a terminal or a lead. Whiskers grew long enough to bridge these intervening

gaps. As a result, both resistors and tubular capacitors have required servicing to correct low impedance conditions.

Failures of a number of selector switches have been caused in a similar manner. The switch case normally is electrically separated from the contact members by means of an insulating disk. However, in some instances whiskers growing on the case have been long enough to extend beyond the disk and make physical contact with an exposed terminal.

Individual units of many assemblies are interconnected by means of leads or cables terminated by connectors such as the AN type. Frequently these connectors are made of aluminum alloys but are given a final tin coating. A number of low-voltage circuits have been examined after low impedances were reported. It was found that whisker growth had developed on the inside surfaces of the connector shells and that some of the whiskers had bridged across to individual contact elements.

Evacuation or maintenance in an atmosphere of inert gas will not prevent the development of whiskers on a component. In Fig. 12 is shown an evacuated glass-enclosed quartz crystal resonator. Whiskers which grew on the crystal tin-plated support wires are clearly visible in Fig. 13. Similar growths have been observed in other

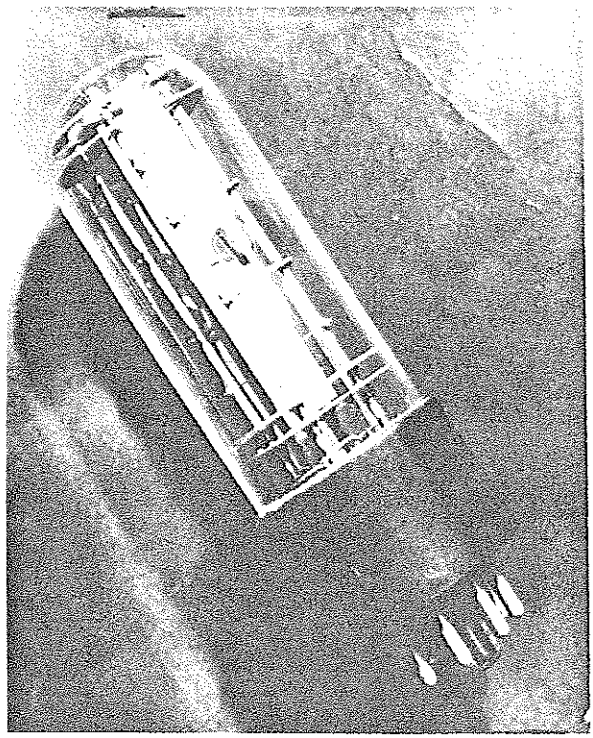

Fig. 12. Glass-enclosed quartz crystal resonator (1.5X).

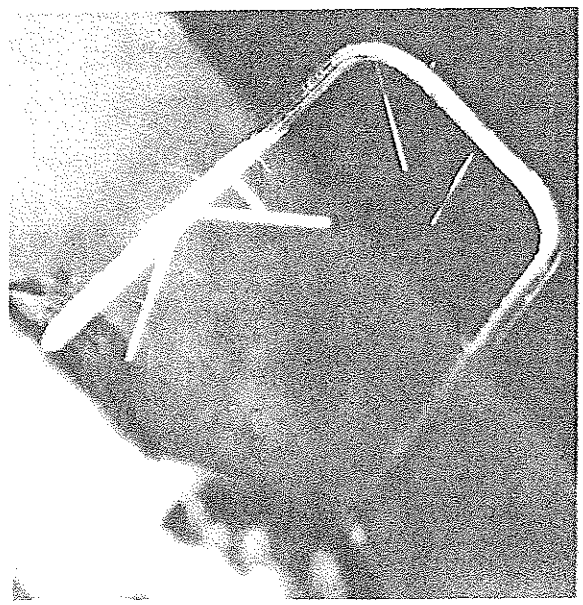

Fig. 13. Tin whiskers growth on support wires in resonator (18X).

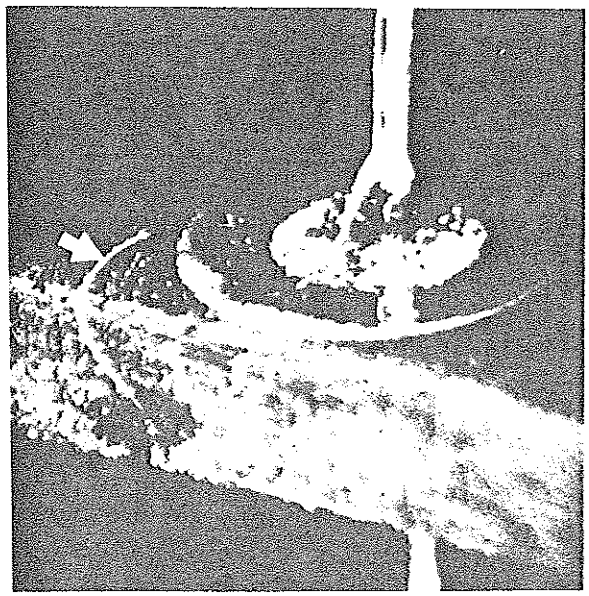

Fig. 14. Whiskers growth on solder fillet in resonator (48X).

units maintained under nitrogen at low pressure. The solder fillet at the attachment area of the crystal in one of these units is shown in Fig. 14. Whiskers have developed on the solder to a length sufficient to reach the edge of the quartz, made contact with similar whiskers growing from the fillet on the opposite face, and short circuit the unit.

Reference has just been made to the occurrence of whiskers at the joint in the quartz crystal resonator. The growth of whiskers from soldered joints in general has not occurred; it is believed that in this

instance the high-frequency vibration of the piezoelectric quartz produced stresses in the solder joint and initiated whisker growth. Laboratory studies of identical units have shown whisker growth only at the joint of crystals being vibrated.

Immersion of a component part in oil also has been suggested as a means of preventing the formation of whiskers. Figure 15, however, shows that a tin-coated bracket immersed in a medium viscosity hydrocarbon oil immediately after it was electroplated is covered with a substantial growth of whiskers.

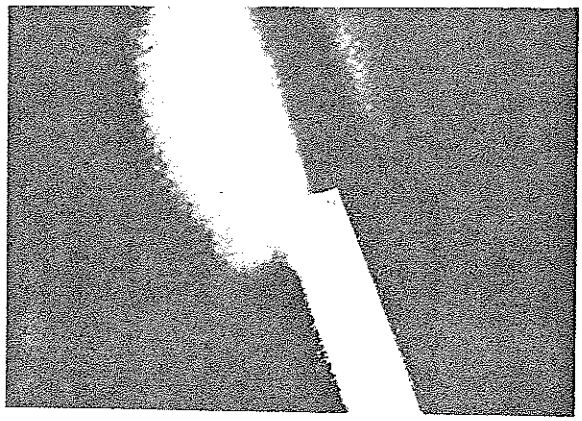

Fig. 15. Whiskers growth from tin-plated part submerged in oil (12X).

The use of a duplex electroplate (first cadmium and then tin) is still another suggested approach to the problem of obtaining finishes not susceptible to whisker growth. This coating, however, will not insure the absence of whisker growth. Whiskers may develop on tin deposited over cadmium or even from tin codeposited with cadmium. A number of coatings of this type are currently under study and will be discussed in a later paper.

Precautionary Measures

There are various procedures that may be followed to reduce or prevent whisker growth, although at present no universally applicable solution is known. Circuit elements must be considered on an individual basis with respect to the need for preventive measures. A service interruption due to whisker growth may be merely an annoyance, to be remedied if and when it occurs; or an interruption may be catastrophic, to be prevented regardless of the effort involved. This last may require the use of a different metallic finish or the redesign of a component for complete assurance of freedom from whisker troubles.

Because of the susceptibility to whisker growth of coatings of tin, zinc and cadmium it may be necessary to curtail their use on specific components. In many instances, it will be feasible to use substitute metallic finishes or even make use of nonfinished parts in critical areas. Thus, electrodeposited nickel, chromium or copper may be specified. If ease of solderability is a requirement, silver or gold may be plated in selected areas. The substitution of silver is subject to some restriction, however, in that silver migration into insulation is a possibility under the influence of a standing potential, and silver may develop a filamentary growth, "hair silver," in an atmosphere of volatile sulfur compounds. Phosphor bronze, brass or other copper alloys, corrosion-resistant steels, aluminum or magnesium alloys often may be left unfinished.

Enhanced whisker growth is to be expected on the thinner electrodeposited coatings. The initially deposited layers of a plated coating are known to be highly stressed and, as mentioned previously, all of our experimental evidence to date points to a stress-induced whisker growth mechanism. The internal stresses decrease with increase in coating thickness, and the heavier coatings therefore are to be preferred when the possibility of whisker growth must be considered.

If a tin coating be fused after electroplating, there will be a marked reduction in whisker growth, probably because of the opportunity afforded for stress relief.

The use of hot-dipped, rather than electroplated, coatings also will result in a major reduction in the growth of whiskers. Several factors are involved here--the coatings are usually thicker, there may be the formation of an alloy layer with the basis metal, and the metal deposited in the molten condition is probably less highly stressed.

As pointed out in the discussions of the whiskers in the relay spring pileup, compressive stresses greatly accelerate whisker growth. Thus, whisker growth

may be anticipated on a tin-coated surface, for instance, where it is subjected to a high bearing pressure from another member. A barrier may be required between closely spaced circuit elements in such an area if high static stresses cannot be avoided.

Where tin-coated parts are involved, maintenance of low relative humidity and low temperature will reduce, although not entirely prevent, the growth of whiskers.

Conclusion

Obviously there are multitudes of electrical circuits which are functioning satisfactorily and which will continue to do so without reason to suspect untoward difficulties. Nevertheless, as has been shown in this discussion, metal whiskers have been associated with a rather diverse group of components. While no attempt has been made to compile a complete list, enough examples have been given to indicate the range of component types which have in the past, and may in the future, provide opportunities for circuit troubles because of whisker growth. Particularly in closely spaced or miniaturized equipment, design and metal finish cannot be specified with quite the freedom allowed where widely spaced parts are involved.

Precautionary measures are possible, and a number have been suggested. While the possibility of whisker growth troubles may seem remote in many installations, some consideration should be given to the question of what may happen and how serious would be the consequences should a spacing be bridged by a conducting filament.

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