proceedings

31st relay conference

April 26, 27, 1983
STILLWATER, OKLAHOMA

SPONSORED BY: OKLAHOMA STATE UNIVERSITY AND
THE NATIONAL ASSOCIATION OF RELAY MANUFACTURERS

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1982 Awards

The National Association of Relay Manufactures and the School of Electrical and Computer Engineerng, in recognition of the outstanding work of the following authors in preparing and presenting their papers, bestowed to them the honorary award, "Fellow in the College of Relay Engineers" at the 1982 Conference.

D. Scott Sink*
School of Industrial Engineering
Oklahoma State University

"THE PRODUCTIVITY ACTION TEAM PROCESS:
AN AMERICAN INVOLVEMENT STRATEGY"

James R. Morton**
Elec-Trol, Inc.
Saugus, CA

HIGH STABILITY CONTACT
RESISTANCE MONITORING CIRCUITS"

Jan Kafka
Standard Telephone and Radio
ITT Associate
Zurich, Switzerland

A PLASTIC-ENCAPSULATED, ELECTRO-MECHANICAL SUBMINIATURE RELAY FOR APPLICATION IN TELEPHONY"

Carl Knox***
Babcock Electro-Mechanical, Inc.
Costa Mesa, CA

Harry Sauter
Potter & Brumfield Div.
AMF, Inc.
Princeton, IN

THE STATISTICAL APPROACH TO
QUALITY -- WHAT? WHY? AND
SHOULD WE?

George Neff
Jimmie K. Neff
Isovac
Glendale, Ca

"EVALUATION OF HERMETICITY
PROBLEMS IN ALL TYPES
OF RELAYS"

---

*The Charles Schneider Best Paper Award of $1000 was awarded to D. Scott Sink.

**The $500 Charles Schneider Award was awarded to James R. Morton.

***The $200 Charles Schneider Award was awarded to Carl Knox and Harry Sauter.

PREFACE

This publication is a compilation of the papers presented at the 31st Annual National Relay Conference held at Oklahoma State University April 26 and 27, 1983. This conference is co-sponsored by the National Association of Relay Manufacturers and the Oklahoma State University School of Electrical and Computer Engineering.

This conference endeavors to provide a forum for the open exchange of information between relay manufacturers and users and for the frank discussion of their mutual problems. The objective being that of improving the manufacturer's ability to supply reliable relays to meet the user's requirements and to help the user properly apply relays.

Papers presented at the conference are screened by a Paper Selection Committee composed of members from relay users, manufacturers, and educators. An expanded abstract of each paper is evaluated by the committee, and those meeting certain standards of quality and technical excellence and possessing the most potential benefit to the relay industry are selected for the program. The author and his affiliation remain anonymous in the selection of the papers.

Special recognition is hereby made to the authors, for without their effort in preparing and presenting their papers, this publication would not be possible. Our appreciation is also expressed to the staff of the Office of Engineering Extension for their work in arranging for the facilities and for supervising the development and sending of the conference publicity. We also express our appreciation to Professor Dan Lingelbach and the School of Electrical and Computer Engineering for their devoted untiring efforts toward conducting increasingly beneficial conferences each year.

The 32nd Annual National Relay Conference is scheduled for April 16, 17, and 18, 1984, at Oklahoma State University.

About The Authors

Session Chairmen

E. Day

Earl Olsen

Mr. Day joined Wabash Relay and Electronics in 1966 to design logic systems using reed relays and solid state components. He was responsible for the initial design of reed switch test equipment that has become the basis for the modern electronic switch testing equipment in use today. Subsequent efforts involved development of computer controlled relay testers and large scale reliability test equipment.

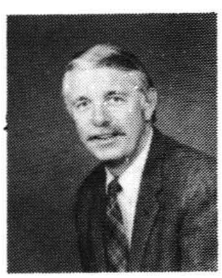
He has held various engineering and supervisory positions. Currently, as Director of Engineering and Development he is responsible for the company's total engineering program. Mr. Day has been very active in NARM technical committees, having served as chairman of the Reed Relay Standardization Committee and the 1981 Relay Conference Coordinating Committee.

Earl Olsen is Relay Sales Manager for Cornell-Dubilier Electronics. Prior to joining Cornell-Dubilier in 1969 he spent 6 years with Magnecraft Electric Company, another 3 years with Cornell-Dubilier and 8 years with C. P. Clare and Company.

Mr. Olsen graduated from the Illinois Institute of Technology in 1960 with a BSEE after having spent several years in the U.S. Army.

He is a Registered Professional Engineer in North Carolina and a Licensed Real Estate Broker in North Carolina.

He has been active in NARM since 1957 serving a term as Vice President of Marketing and a year as Relay Conference Coordinator.



Ed Sutherland

Wayne Wielebski

Ed Sutherland is President of Relay Testing Services, Inc. He graduated from Cornell University in 1955 with a Bachelor of Science degree in Electrical Engineering. After 19 years in various marketing and technical positions with General Radio (now GenRad) and Teradyne, Mr. Sutherland founded Relay Testing Services in 1975. He is the author of five papers on relay testing, is a Fellow in the College of Relay Engineers (1977 and 1981) and a winner of the NARM Charles Schneider Best Paper Award in 1977.

Wayne Wielebski is a graduate of the University of Wisconsin where he earned a Bachelor's Degree in Electrical Engineering (1964) and a Master's Degree in Electrical Engineering (1972). Mr. Wielebski joined the Allen-Bradley Company, Milwaukee, Wisconsin in 1974 where his present position is Manager of the Control Device Development Department. His previous position was that of Manager for Solid State Product Development. He has made a career in development and design of products and components for the Industrial Control market that includes electromechanical, solid state, and sealed switch technologies.

THE INFLUENCE OF CRITICAL MANUFACTURING VARIABLES UPON FATIGUE LIFE OF SPRINGS

By **J. C. Warner,** Manager, Metallurgy & Physical Test Laboratories, Allen-Bradley Company, Milwaukee, WI 53204.

J. Warner directs the Department of Metallurgy and Physical Testing at Allen-Bradley, developing applications for improved materials and instituting new processing technology for metals applications, including machining, forming, joining, and plating. His previous experience includes materials research on heat exchangers, and development of alloys and processing for vacuum brazing aluminum.

He produced an animated film on metallurgical applications of thermodynamics while at Carnegie-Mellon University, and holds a Ph.D. in metallurgy from Iowa State University. His favorite hobby is operating his Apple computer.

AUTOMATED MANUFACTURING OF RELAY COIL ASSEMBLIES

By **Jon M. Miller,** Senior Engineer, Western Electric Company, Columbus, Ohio 43213.

Jon. M. Miller is a Senior Engineer in the Apparatus Manufacturing Department at the Western Electric Company, Columbus, Ohio. His current assignments include LR Relay Assembly and Test, LR Relay Coil Winding and Finishing, and Miniature Wire Spring Relay Metal Piece Part Secondary Operations. Mr. Miller joined Western Electric in 1969 after receiving a Bachelor of Science Degree in Industrial Technology from Ohio University. His past assignments have included G.P. and Miniature Relay Coil Winding and Finishing along with Relay Final Assembly and Adjusting. He is a member of the Society of Manufacturing Engineers and the International Coil Winding Association.

Jon. M. Miller

About The Authors

AUTOMATED MANUFACTURING OF RELAY COIL ASSEMBLIES

By **Forrest G. Sheeler,** Development Engineer, Western Electric Company, Columbus, Ohio 43213

Forrest G. Sheeler is a Development Engineer in the Circuit Pack and Apparatus Test Department at the Western Electric Company, Columbus, Ohio. After attending Ohio State University and receiving an Associate Degree in Electrical Engineering from Ohio Technical College in 1966, he joined Western Electric at the Columbus Works. His current assignments include the development of test programs and test systems for circuit pack and LR low-profile relay. Mr. Sheeler has worked on testing apparatus for ferreed switches, ferrod sensors, ladder transformers, computer-controlled functional testing of the remreed switch and remreed grid, inductors and dry reed relays.

THE ADVANTAGES OF USING RELAYS IN THE EVER CHANGING MARKET PLACE

by **Don Krause,** Relay Marketing Manager, Guardian Electric Manufacturing Company, Chicago, Illinois 60607.

Don Krause graduated from College of DuPage in 1974, with an Associate Degree in Business Management. He has been involved in the electronics markete for the last seven years. In 1979 he joined Guardian's Sales/Marketing team, and presently holds the position of Relay Marketing Manager.

THE BOUNCLESS ELECTROMAGNETIC RELAY

By **Kunio Mano,** Professor and Doctor, Graduate School of Engineering, Meijyo University, Nagoya, 468 Japan.

Professor Kunio Mano was born in Aichi Prefecture, Japan on September 29th, 1910. He received the B.S. and Ph.D. degrees in Electrical Engineering from Tohoku University, Sendai, Japan, in 1937 and 1960 respectively.

In 1948, he became an Assistant Professor, and in 1954 he became a professor in the Department of Electrical Communication Engineering, Tohoku University. In 1974, he was made a Professor Emereitus of Tohoku University, now he is a Professor in the Department of Electrical Engineering and the Graduate School of Engineering of Meijyo University.

Dr. Mano is IEEE fellow, the Institute of Electronics and Communication Engineers of Japan, the Society of Instrument and Control Engineers, and so on.

Dr. Mano has been active academically in the Electronics and Electrical Engineering field. He was awarded a Violet Ribbon Medal from his Majesty the Emperor for his work and also received the Ranger Holm Scientific Achievement Award.

By **Toshiaki Eguchi**, Student, Graduate School of Engineering, Meijyo University, Nagoya, 468 Japan.

Toshiaki Eguchi was born in Aichi Prefecture, Japan on November 2, 1957. He received the B.S. degree in Engineering from Meijyo University, Nagoya, Japan, in 1981, and he advanced the Graduate School of Engineering in Meijyo University in 1981.

He is studying the life reliability of electromagnetic relay with and without electrical bounceless circuit in Mano Laboratory.

Mr. Eguchi is a student member of IEEE, an associate member of the Institute of Electronics and Communication Engineeres of Japan, and a member of the Institute of television engineers of Japan.

THE RELATIONSHIP BETWEEN COIL ENERGIZATION IN A RELAY AND REED CONTACT PERFORMANCE

By **B. M. Tieman,** Drs., Nederlandse Philips Bedrijven B.V., 6416 SG Heerlen, The Netherlands.

Ben M. Tieman has been with Philips since his graduation in chemistry from the University of Leiden in 1979. From then until 1981 he worked on the development and application of reed contact units. He presently holds the position of Chief Engineer concerned with the development and production engineering of reed contact units.

GETTERS IN RELAYS—A USEFUL TOOL TO INCREASE RELIABILITY

By **Ernst Weber,** Dr. rer. nat., SDS-Elektro GmbH, 8024 Deisenhofen, FRG. 00 49 89 / 6 13 20 61

-Ernst Weber was born in Berchtesgaden, West Germany, on September 25th, 1947.

-After school and military service study of physics at the "Technische Universitat Munchen" 1968 through 1974; thesis in solid state physics.

-1975 through 1978, work on doctoral thesis in the field of solid state physics, especially in biophysics.

-Meanwhile, since 1974 to mid 1980, assistant at the Max Planck Institute of Biochemistry.

-Since mid 1980, member of the research and development laboratory of SDS-Elektro GmbH in Deisenhofen near Munch and mainly engaged in quality and basic relay problems.

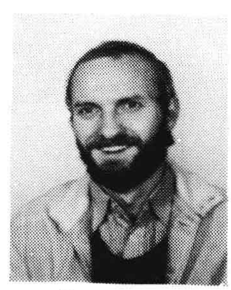
Forrest G. Sheeler

Don Krause

Kunio Mano

Toshiaki Eguchi

B. M. Tieman



Ernst Weber

About The Authors

CONTACT RELIABILITY EVALUATION OF PLASTIC SEALED RELAY

By **Takeshi Sasamoto,** Associate Chief Engineer, Engineering Department, Electromechanical Device Division, Tokyo 108, Japan.

Takeshi Sasamoto received Ph.D. Degree in Engineering from Tohoku University, Sendai, Japan in 1979. Prior to joining NEC in 1960, he studied at the Electrical Telecommunication Laboratory of Nippon Telegraph and Telephone Public Corporation. He is now Associate Chief Engineer of Electromechanical Device Division. He is a member of the Institute of Electronics and Communication Engineers of Japan.

By **Toshifumi Sakurai,** Reliability and Quality Control Department, Electromechanical Device Division, Tokyo 108, Japan.

Toshifumi Sakurai received the Bachelor of Science degree in Department of Material Science from Tokai University in 1980. He joined NEC in 1980, and has been engaged in the development of electromagnetic relays. He is member of Reliability and Quality Control Department, Electromechanical Device Division.

By **Tatsumi Ide,** Supervisor, Engineering Department, Electromechanical Device Division, Tokyo 108, Japan.

Tatsumi Ide received the Bachelor of Science degree in Electrical Engineering from Tokyo Electrical Engineering College in 1972. He joined NEC in 1967, and has been engaged in the development of reed contacts and electromagentic relays. He is now Supervisor of Engineering Department Electromechanical Device Division.

A MISCONCEPTION CONCERNING NORMAL AND INTRINSIC CURVES OF PERMANENT MAGNETS

By **George B. Pratt,** Electromechanical Engineer, Tektronix, Inc., Delivery Station 58-021, P.O. Box 500, Beaverton, Oregon 97077.

George Pratt attended Oregon State University and the University of Santa Clara. He has been involved in the design of relays and other small electromechanical devices for several years, with previous experience in quality control assignments. He previously presented a paper at the 1973 NARM Conference.

His hobbies include hiking, classical music, mathematical recreations and technological antiques.

PERMANENT MAGNET MATERIALS AVAILABLE FOR USE IN RELAYS

By **Dan C. Sloss,** Design & Applications Engineer, Colt Industries, Crucible Magnetics Div., Elizabethtown, Kentucky 42701

B.S. Industrial Education, Western Kentucky University, 1970.

M.A. Education/Industrial Education, Western Kentucky University, 1971.

Former Educator.

Has served as Crucible's Cost Reduction Coordinator, Jr. Industrial Engineer, and now is Associate Design and Applications Engineer for all of Crucible Magnetics product lines.

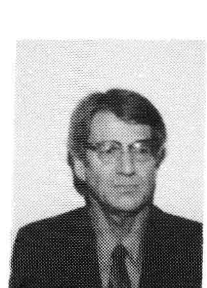
By **John J. Du Plessis,** Vice President of Technology & General Mgr. Alnico Operation, Colt Industries, Crucible Magnetics Div., Elizabethtown, Kentucky 42701

John DuPlessis is a graduate of North Carolina State University with degrees in Mettalurgy, Ceramics, and Physics. He has been associated with the development and manufacturing of permanent magnets since 1960. He has held positions in Quality Control, Manufacturing Supervision, and Technology Development in the Ferrite, Rare Earth Cobalt and Alnico systems with the Crucible Magnetics Div. of Colt Industries. Currently he is Vice President of Technology for the Magnetics Division and also is General Manager of the Alnico operation.

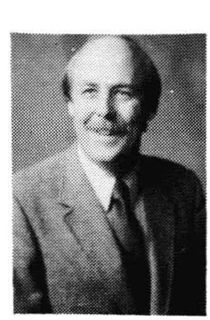
Toshifumi Sakurai

Tatsumi Ide

Takeshi Sasamoto



George B. Pratt



Dan C. Sloss

About The Authors

NEW SEMI-HARD MAGNETIC ALLOY AND ITS APPLICATION TO REMNANT REED SWITCHES

Takoa Yano

Mr. Yano was born in Hokkaido, Japan, in 1939. He was graduated from Tokyo Rika University in 1963 and received the B.S. degree in Physical Engineering.

He has been employed by OKI Electric Industry Co., Ltd., Tokyo, Japan, since 1963.

He was engaged in the development of Reed Switches and is now a manager of engineering section, Electro Mechanical Components Department.

He is a member of the Institute of Electronics and Communication Engineers of Japan.

Tsutomu Soda

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He has been employed by OKI Electric Industry Co., Ltd., Tokyo, Japan, since 1972.

He was engaged in the development of Reed Switches and is now a supervisor of engineering section, Electro Mechanical Components Department.

He is a member of the Institute of Electronics and Communication Engineers of Japan.

Osamu Kawai

Mr. Kawai was born in Shizuoka, Japan, in 1949.

He was graduated from Electronics Communication University in 1974 and received the B.E. degree in Physical Engineering.

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CHARACTERISTICS OF REEL RELAYS UNDER MECHANICAL SHOCKS

By **Bogdan Miedzinski,** Ph.D. Asst. Professor, Technical University of Wroclaw, Institute of Electr., Power Engng. 50-310 Wroclaw, Poland. 203-693

B. Miedzinski received the M.Sc and Ph.D. degrees from the Technical University in Wroclaw, Poland in 1967 and 1971 respectively. He joined in 1967 the Electrical Power Systems Institute of Technical University in Wrocklaw. In 1978-79 he worked as Visiting Asst. Professor at Texas Tech University in Lubbock /USA/. At present he is involved in the study of various aspects of open and sealed contact phenomena with particular emphasis on application of the reed switches as measuring as well switching devices in Automated Electrical Power System. Dr. Miedzinski holds several patents and has published extensively.

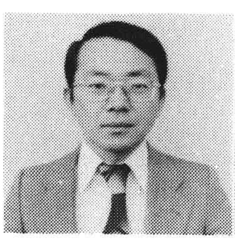
By **Tadeusz Zolnierczyk,** Ph. D., UNITRA-DOLAM, Wroclaw, 50-426 Wroclaw, ul. Krakowska 56/78, Poland. 44-50-41 /w.378/

T. Zolnierczyk received his M.Sc. and Ph.D. from the Technical University of Wroclaw, Poland in 1969 and 1977 respectively. At that time, he joined the Unitra-Dolam Company/Wroclaw/where he is now a Member of Technical Staff. His specialities are gas - and vacuum contact device technology and reliability physics of sealed contact devices. He is the author and co-author of numerous papers in learned journals.

FULLY AUTOMATED TEST SYSTEM COMBINING LIFE TEST, DATA LOGGING AND STATISTICAL ANALYSIS FOR RELAY CONTACT CHARACTERIZATION

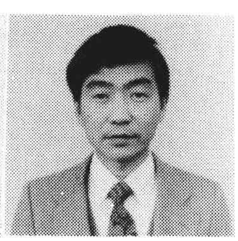
By **Bruce Campbell,** Vice President, Coto Corporation, Providence, Rhode Island 02905.

Bruce D. Campbell is Vice President of Coto Corporation. He is a graduate of the University of Rhode Island, with a B.S. in Physics and Brown University with a Ph.D. in Physics. After graduation he held research appointments in surface physics at Brown University and Los Alamos Scientific Laboratory. He then worked for IBM as a development physicist in bipolar and FET memories. In 1969 he joined Coto Corporation and has since headed up their reed relay and test equipment development effort.

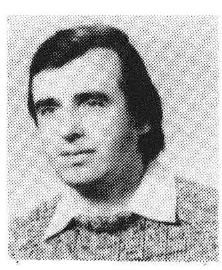


Tsutomu Soda

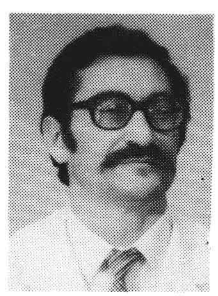
Osamu Kawai



Takao Yano



Bogdan Miedzinski



Tadeusz Zolnierczyk

Bruce Campbell

About The Authors

By **John Beigel,** Chief Engineer, Coto Corporation, Providence, Rhode Island, 02905.

John Beigel attended Northeastern University, New York University and the University of Lowell receiving his B.S. and M.S. in Physics. He has since designed and developed Reed and Solid State Relays at EI&S for approximately nine years. For the past two years he has been heading up the engineering department at Coto Corporation as their Chief Engineer.

By **Allan Rydberg,** Senior Design Engineer, Coto Corporation, Providence, Rhode Island 02905.

Allan Rydberg is Senior Design Engineer at Coto Corporation where he is involved in designing automatic test equipment for reed relays. Mr. Rydberg holds a B.S. in Physics from the University of Rhode Island and has also attended Brooklyn Polytechnic Institute and the City College of New York.

ANALYZING THE REAL COSTS OF DEFECTIVE REED RELAYS

By **Robert H. Gusciora,** Technical Specialist/Project Manager, Xerox Corporation, Rochester, New York 14623

Robert H. Gusciora is a Technical Specialist/Project Manager in the Electronics Division of the Xerox Corporation. During 19 years with the company, Mr. Gusciora has held various engineering and management positions concerning the development of electrical, electronic, and electromechanical components. His primary have nurtured special interests in the engineering management of quality and in the development of methods of minimize component quality problems prior to production. Present assignments are primarily associated with solid-state relays and contractors.

Mr. Gusciora is a 1964 graduate of the University of Massachusetts (BSEE). He is a Member of the IEEE and the Ad Hoc Advisory Committee for IEC SC28A (Insulation Coordination of Low-Voltage Equipment). Inside and outside of Xerox, Mr. Gusciora has been responsible for a number of technical papers and presentations. Two papers were presented at NARM Conferences (1977 and 1979). For each, Mr. Gusciora was bestowed the honorary award, "Fellow in the College of Relay Engineers," and for the 1979 paper, Mr. Gusciora received the Charles Schnieder Best Paper Award.

In his spare time, Mr. Gusciora and his wife enjoy sailing, tropical travel, and gardening.

PARAMETRIC RELAY TEST SYSTEM ARCHITECTURE AND APPLICATIONS

By **James R. Morton,** Manager of the Test Engineering Department, Elec-Trol, Incorporated, Saugus, California 91350.

Jim Morton received his B.S.E.E. with honors from New Mexico State University in 1975. Subsequently he was employed by Rockwell International B-1 Bomber Division, Bendix Electrodynamics Division, and FMC Agro-Electronics.

Since January 1980 Jim has been at Elec-Trol, where he is the Manager of the Test Engineering Department. Jim is responsible for maintaining all present equipment, and the design, development, and production of new equipment. He has brought several microprocessor-based test systems into production use; these systems are used in reed sorting, reed sealing, final test, and life testing.

Jim enjoys family activities with his wife and three sons. His remaining time is taken up by photography and target shooting.

RELAY DESIGN FOR APPLICATION IN ENERGY MANAGEMENT SYSTEMS

By **Leon Britton,** Chief Engineer - Special Products Division, Guardian Electric Manufacturing Company, 1550 West Carroll Ave., Chicago, Illinois 60607.

Leon graduated from DeVry Technical Institute, Chicago, Illinois in 1950. He subsequently attended Northwestern University in Evanston, Illinois.

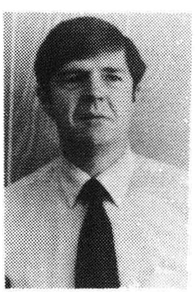
From 1951 to 1969 he was employed by the Seeburg Corp. in Chicago in a variety of technical positions involving both electrical and mechanical design of Electromagnetic products.

He joined Guardian Electric in 1969 as Senior Project Engineer. In 1979 he attained his present position of Chief Engineer, Special Products Division. Guardian's new products in the Power Management area are the results of Leon's personal contribution to the Special Products Division.

DEVELOPMENT OF HIGH CURRENT REED SWITCH USING COBALT-IRON ALLOY

By **Akira Tanaka,** The Magnetics Society of Japan, 460 Oaza-Koyama, Suzaka-Shi, Nagano-Ken, 382 Japan.

Mr. Tanaka was born on March 18, 1946. He received his Master's and Doctor's degrees in Polymer Science from Osaka University. His present position is as a Senior Engineer in the Electro-Mechanical Components Department of Fujitsu Limited where he is engaged in the development of reed switch.



John Beigel

Allan Rydberg

Robert H. Gusciora

Jim Morton

Leon Britton

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About The Authors

DEVELOPMENT OF HIGH CURRENT REED SWITCH USING COBALT-IRON ALLOY

By **Masanori Baba,** The Institute of Electronics and Communication Engineer of Japan. 460 Oaza-Koyama, Suzaka-Shi, Nagano-Ken, 382 Japan.

Mr. Baba was born on October 26, 1945. He graduated from Ibaraki University in 1969. His present position is a Senior Engineer in the Electro-Mechanical Components Department of Fujitsu Limited where he is engaged in the development of reed switch.

By **Oshiro Oguma,** The Institute of Electronics and Communication Engineer of Japan. 460 Oaza-Koyama, Suzaka-Shi, Nagano-Ken, 382 Japan.

Mr. Oguma was born on May 26, 1942. His working experience includes being engaged in the development of a semi-hard magnetic reed switch from 1969 to 1971 and the development of production engineering of reed switches from 1971 to 1976. His present position is as a Section Manager in the Electro-Mechanical Components Department of FUJITSU LIMITED where he is engaged in the development of reed switches.

THE DEVELOPMENT OF A HIGH RELIABILITY HIGH G SHOCK RELAY, A NEW DESIGN CONCEPT

By **Max Hurter,** Director of Engineering, Babcock Electro-Mechanical, Inc., 3535 Harbor Blvd., Costa Mesa, CA 92626

Max Hurter is Director of Engineering, Electromechanical, for Babcock Electro-Mechanical, Inc. in Costa Mesa, California, where he is responsible for research as well as application engineering. Prior to joining Babcock in 1970, Mr. Hurter was manager of relay operations at Bourns, where he developed new designs of both military and industrial micro-miniature relays. He came to Bourns from Square D Company in Milwaukee. Mr. Hurter received an advanced degree in electrical engineering from Technikum of Wintherthur in Switzerland, where he worked in relay design for eight years prior to coming to America.

Masanori Baba

Toshiro Oguma

Max Hurter

MINIATURE POLARIZED RELAYS WITH NEW TECHNOLOGY

By **Shigeru Tajima,** Manager of Relay Design, Matsushita Electric Works, Ltd., 1048, Kadoma Kadoma-city Osaka-pref. 571, Japan.

Shigeru Tajima received the Bachelor of Science degree in Electrical Engineer from Tohoku University in 1964.

He joined Matsushita Electric Works, Ltd. in 1964 and has been engaged in the research and development of Relays.

He is now Engineering Manager of Relay Development Department Precision Electric Controls Division.

By **Masahiko Nakajo,** Engineer of Relay Product Engineering, Matsushita Electric Works, Ltd., 1048, Kadoma Kadoma-city Osaka-pref. 571, Japan

Masahiko Nakajo received the Bachelor of Science degree in Mechanical Engineer from Niigata University in 1966.

He joined Matsushita Electric Works, Ltd. in 1966 and has been engaged in the development of Product Engineering. He is now Engineer of Relay Product Engineering Section Precision Electric Controls Division.

By **Kenji Ono,** Engineer of Relay Design, Matsushita Electric Works, Ltd. 1048, Kadoma Kadoma-city Osaka-pref. 571, Japan.

Kenji Ono received the Bachelor of Mechanical Engineer from technical high school of Wakayama-pref. in 1965. He joined Matsushita Electric Works, Ltd. in 1965 and has been engaged in the research and development of Relays. He is now Engineer of Relay Development Department in Precision Electric Control Division.

By **Doug Kuffel,** Sr. Engineering Manager, Engineering Division, Aromat Corporation, 10400 N. Tantau Avenue, Cupertino, CA 95014, U.S.A.

Doug Kuffel graduated from Milwaukee United Technical Institute in 1969. He joined Honeywell in 1969 as a Field Engineer for the Industrial Products Group.

In 1974 he joined Hamlin, Inc. as an Applications Design Engineer.

Since 1978, he has been with Aromat Corporation, Engineering Division. He is now the Sr. Engineering Manager for Aromat.

He is presently attending San Jose State University to complete his B.A. in Business Administration.

Shigeru Tajima

Masahiko Nakajo

Kenji Ono

Doug Kuffel

TABLE OF CONTENTS

THE INFLUENCE OF CRITICAL MANUFACTURING VARIABLES UPON FATIGUE LIFE OF SPRINGS

L. Stankowski and J. Warner
Allen-Bradley Company
Milwaukee, Wisconsin

SUMMARY

Allen-Bradley Company manufactures numerous devices for use in a corrosive environment that incorporate springs of various shapes and sizes. These springs, with their expected reliability, are often made of stainless steel. This report discusses the relationship of surface texture of stainless steel springs to fatigue life and shows that rough surface texture is a deciding factor in premature fatigue failures.

INTRODUCTION

Allen-Bradley has been monitoring the performance of different lots of stainless steel springs in the laboratory for some time to help assure quality. A standard laboratory test subjects the springs to high fatigue loading, i.e., the combination of maximum stress and required cycle life places the spring near the fatigue limit curve, Figure 1.

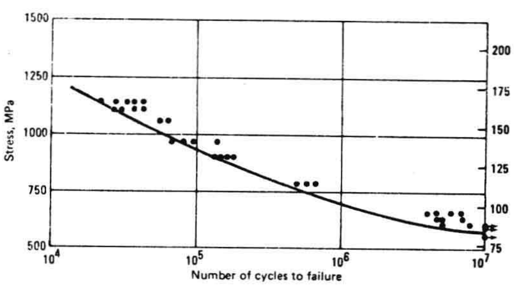

FIGURE 1 S-N Diagram for 0.022" dia. music wire, from Ref. 1.

A dramatic increase in failures in the standard laboratory test in recent years led to significantly increased inspection costs and production delays.

To help assure acceptable springs, an additional program was established to evaluate by fatigue testing all lots of certain springs prior to acceptance. The choice of springs to be tested was made on the basis of the above mentioned test data. As the percentage of rejected lots increased to over 20%, it became clear that some lots of springs had very low quality. Quality did not suffer a general decline. Rather, certain lots failed utterly while others passed easily. This result is consistent with a decline in spring quality over the past decade.[1] In Reference 1 it is noted that spring fatigue performance, while previously good, has become "variable".

The present study was undertaken to (a) determine the apparent differences between excellent and poor stainless springs, (b) establish the source of these differences, and (c) determine acceptable operating limits.

ANALYSIS

A specific spring which a quality vendor could supply was selected for initial study. The spring, made from 0.012" diameter type UNS 30200 stainless steel wire, is 0.145" mean coil dia., 0.645" free height, with nominal 12-1/2 coils and unground closed ends. Wide variations in fatigue life had been found on shipments of this spring. Detailed study of the actual spring operation suggested that it could go down to near solid height of 0.150" in use, so laboratory fatigue tests used a range of 0.420 to 0.150" at 6 Hz.

In the case of one lot of these springs, this test was terminated at 495,000 operations, when 4 springs failed out of 25 tested. Had these springs been used to build operating devices, the same proportion of failures would be anticipated, in a somewhat larger number of cycles.

In Figure 2 are scanning electron micrographs at 100X and 700X illustrating the surface condition of a spring that was tested to 20.1 x 10^6 operations with no fracture in a laboratory device test. Figure 3 illustrates the surface condition and the fracture mode of a spring that failed at 197,000 cycles in the same laboratory test. Figure 4 shows a spring that fractured during the fatigue test. The fracture modes in both the device tests and fatigue tests are the same. Fatigue fractures nucleate on the I.D. of the spring, at a groove in the surface. The fatigue fracture surface from both device tests and fatigue tests occupy 30% to 50% of the total fracture surface.

Figures 2 through 4 indicate that the rough surface condition is a major factor in fatigue failures. Notches or small surface cracks are natural stress risers, so this result is not unexpected.

A fatigue test of this same lot of springs was performed to determine whether shot peening could improve the fatigue properties significantly. Although the shot peened springs performed better, they were still susceptible to early fatigue failures. Paralleling this fatigue test result was a failure of a shot peened spring in a laboratory device test at 544,000 operations. The surface conditions and fracture modes of shot peened springs that failed during life testing are illustrated in Figure 5. The fracture surfaces are similar to those in Figures 2-4. The shot peened surface is noticeably smoother than the untreated springs but not as smooth as the spring which exceeded 20.1×10^6 operations. The fractures still initiate at small surface grooves. This result indicates that once the rough surface has been created, subsequent treatment after coiling to a spring is not likely to improve fatigue properties significantly.

Obviously, different drawing practices in the final stages of wire size reduction have a marked effect on the wire surface. A lubricating coating is applied to the wire before drawing to reduce friction and heat. Figure 6 illustrates the surface of wire fabricated by dipping in sulfuric acid, then hot lead, then drawn through tungsten carbide dies. The lead acts as a drawing lubricant. After passivation the etch pits from the sulfuric acid etch are revealed. In the past, the lead coat was applied with the aid of a flouride bearing flux, but environmental and cost restraints promoted a switch. On the other hand, nonmetallic coatings and diamond dies can form a near perfect surface, Figure 7. Unfortunately, diamond dies wear unevenly, producing out-of-round wire which reportedly results in large amounts of out-of-spec springs during coiling.

Figure 8 illustrates a surface that has performed acceptably in fatigue tests. This is a type 302 stainless steel spring, 0.012" diameter, drawn through tungsten carbide dies using a non-hydroscopic phosphate coating developed by a wire fabricator. It reportedly does not flake during the drawing process, coils well, and is removed in hot tap water.

In addition to the springs needing a high quality surface condition, all type 302 stainless steel springs received by A-B must be passivated. In wire manufacturing, the coatings used as lubricants during the drawing process may inhibit the formation of a protective oxide, which is to say, the "stainless" benefit of stainless steel. When they do, corrosive attack begins and surfaces decompose rapidly. The solution is passivation, which hastens the formation of protective oxide films and cleans other foreign matter. Passivation also takes the coating off of the wire, revealing the true surface. Figure 9 illustrates a spring drawn with a copper coating and passivated.
A series of fatigue tests were performed comparing springs from various wire manufacturers using different manufacturing processes. All springs were made from 0.012" diameter stainless steel type 302 wire. Three identical tests were run, each of which contained five springs with wire drawn as described in Table I.

Based on the observed surface of these springs we estimated that the wire of Types 1, 4, and 5 would perform acceptably on fatigue tests. Type 2 was considered to have a undesirable surface and was predicted to perform unacceptably on fatigue tests. Type 3 was between the extremes.

There was a significant difference in surface quality between wire type 2 and 4, even though both used nominally the same drawing process. This observation suggests that specification of wire fabrication methods would not be adequate to ensure product quality.

High speed photography of the spring during its real life motion revealed that a considerable amount of surging and coil clashing may occur. Because of this condition it was decided to use the severe displacement limits of 0.170" and 0.580", so the springs were cycled to very near solid height and free length. A sine wave at 10 cycles per second was the fastest the fatigue machine could cycle under this displacement. Five of each of the five types described above were tested, in each of three fatigue trials, for a total of 15 springs of each type.

Each of the 5 types of springs were measured for wire diameter and spring diameter. The spring rates of the springs were determined using the laboratory Universal Testing Machine. Using these measurements the maximum and minimum stress levels at the lower and upper displacement limits of the fatigue tests were calculated, Table II.

The total results of the 3 fatigue tests showed that 15 out of 15 springs of wire type 2 failed before 235,000 ops. All of the other four types of springs endured 6×10^6 ops. with no fatigue failures. Table III tabulates the results of the fatigue tests. Even though all failed the fatigue tests, the springs of wire type 2 were subjected to the lowest stress levels.

Figure 10, from the Spring Designers Handbook[2], illustrates the recommended design stresses for stainless steel type 302 springs with various diameter wires. The severe service curve is applied for springs that are subjected to over 1.0 X 10^6 deflections. The severe service curve for 0.012" diameter wire shows that the recommended design stress limit is 120,000 psi.

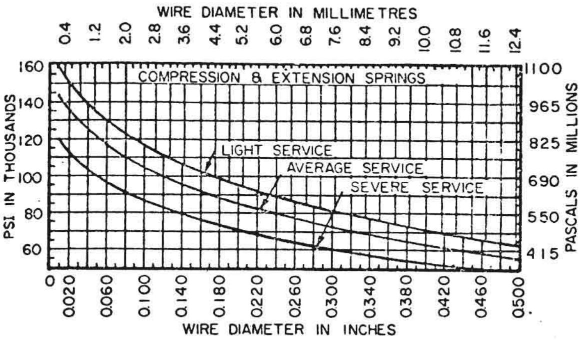

FIGURE 10 Recommended design stresses for UNS 30200 compression springs, from Ref. 2.

Figure 11, from Ref. 3, illustrates the endurance limits for 10^7 deflections for various diameter type 302 stainless steel springs. As expected from the severity of the test, the applied stress levels are above the published endurance limits.

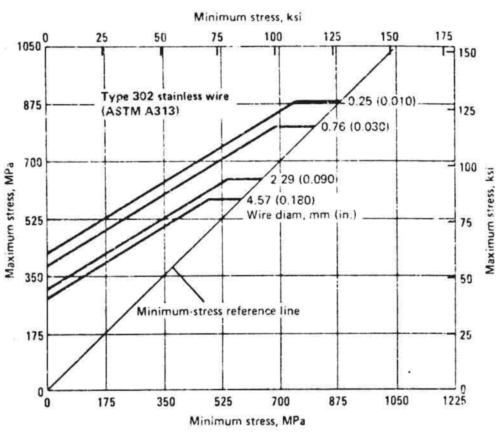

FIGURE 11 Recommended endurance limits for UNS 30200, from Ref. 3.

Many other factors besides rough surface condition can contribute to early fatigue failures. Springs made from unsound wire will fail even with a smooth surface. However, such wire usually fails to coil properly also, and so does not reach our initial inspection. In addition, other inspections of springs subject to high fatigue loads are performed.

CONCLUSIONS

Stainless steel 18-8 type springs manufactured with rough surface wire are subject to low fatigue life under load, while the sound wire tested with a smooth surface met published fatigue lives. All springs of sound wire tested which passed the surface quality inspection surpassed the maximum expected number of cycles in standard laboratory tests and fatigue tests. The surface condition is a direct consequence of wire drawing practice, and can be observed by a trained inspector at 30X magnification. Use of such inspection techniques can allow rapid selection of quality springs, with potential reduction in inspection costs and production delays.

References:

1) Metals Handbook, 9th Ed., American Society for Metals, Metals Park Ohio, 1978, p. 290.

2) Spring Designers Handbook, Harold Carlson, Marcel Dekker, New York, 1978, p. 149

3) Metals Handbook, 9th Ed., op. cit. p. 295

TABLE I

MANUFACTURING METHOD FOR TESTED SPRING WIRE

SPRING WIRE TYPE	WIRE MANUFACTURER	DRAWING LUBRICANT
1	U.S. Mfg. "A"	Copper
2	U.S. Mfg. "B"	Lead
3	U.S. Mfg. "B"	Organic
4	Foreign Mfg. "A"	Lead
5	Foreign Mfg. "B"	Nickel

Note: All of the above wire samples were coiled by one spring maker on one set-up to the dimensions given in the report.

TABLE II

STRESS LOADING ON SPRINGS MADE FROM 5 WIRE SOURCES

WIRE TYPE	AT 0.170" DISPLACEMENT	AT 0.580" DISPLACEMENT
1		
1	98,500 psi	12,200 psi
2	92,900	13,500
3	97,400	14,500
4	105,300	10,900
5	100,800	14,200

Note: Stresses computed from measured spring rates.

TABLE III

FATIGUE TEST RESULTS

5 springs of each type per test
6×10^6 operations per test

TYPE	TEST #1 MTS 302A	TEST #2 MTS 302B	TEST #3 MTS 302C
1	No failures	No failures	No failures
2	5 of 5 failed <218,000 ops	5 of 5 failed <100,000 ops	5 of 5 failed <235,000 ops
3	No failures	No failures	No failures
4	No failures	No failures	No failures
5	No failures	No failures	No failures