IMPROVED M-11 COPPER CRUSHER GAGE

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ABSTRACT

Recent testing of the M-11 Copper Crusher gage indicates that it does not meet the NATO standards for precision at the high end of its operating range. The Ballistic Research Laboratory (BRL), of the Armament Research and Development Command (ARRADCOM), at the request of the Materiel Testing Directorate (MTD), of the Test and Evaluation Command (TECOM), performed structural integrity analyses using the finite element method for mechanical behavior of solids. A design modification to the gage resulted from the analyses.

INTRODUCTION

The M-11 Copper Crusher gage is a self-contained, re-usable pressure gage used to measure peak pressure developed in the chamber of large caliber guns. Recently, the M-11 gage was tested against crusher gages from other NATO nations for precision. The M-11 gage (high pressure) failed to meet the precision requirements of less than 1% (2% for cold temperature extremes) deviation between gages. Table I was extracted from the report on the comparison trials [1] and tabulates the deviations of the gages for each nation at varying pressures and temperatures. The M-11 gage was tested at pressures from 1050 bars (27 Ksi, 186 MPa) to 5500 bars (81 Ksi, 559 MPa). MTD is the primary investigator of the M-11 gage's performance. They performed a similar test of the M-11 gage over the pressure range of 60 to 120 Ksi (414 to 828 MPa) at 72°F (22°C). Figure 1 displays the results of the test of the M-11 gage against the piezo-electric standard gage. The deviation is well beyond the limitations imposed by the NATO standardization agreement.

The BRL was consulted as part of the investigation to perform structural integrity analyses of the gage. The BRL's approach made extensive use of the finite element method for the mechanical behavior of solids. The goal was a modification to the design of the M-11 gage which would correct its operating flaws and extend the operating range to 120 Ksi (828 MPa).

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1. "Third NATO Crusher Gage Comparison Trials 1977, by Order of NATO AC 225 Panel IV," Meppen, FRG, October, 1977.

Table I. Results of the Precision Test Indicating Percent Deviation Between Gauges

Pres. Level* / Temp. Level	FH 155-1 Low Pressure Gages 500 (7.4)	1250 (18.4)	1850 (27.2)	1850 (27.2)	3000 (44.1)	4000 (58.8)	105 mm High Pressure Gages 4000 mean (58.8)	4000 (58.8)	4750 (69.8)	5500 (80.9)	Nation
+ 21°C	1.3	0.5	0.4	0.5	0.4	0.4	0.4	0.4	0.6	0.9	FRG
- 40°C	1.6	0.6	0.5	0.8	0.6	0.8	0.85	0.9	1.0	0.5	FRG
- 10°C	1.2	0.6	0.4	0.5	0.4	0.5	0.5	0.5	1.0	0.7	FRG
+ 60°C	1.2	0.4	0.3	0.4	0.4	0.5	0.55	0.6	0.5	1.0	FRG
+ 21°C	1.0	0.4	0.1	0.8	0.2	0.4	0.3	0.2	0.1	0.3	F
- 40°C	0.5	0.3	0.3	1.3	0.8	1.9	2.05	2.2	1.2	1.1	F
- 10°C	0.7	0.4	0.4	0.3	0.3	0.9	0.8	0.7	0.7	0.7	F
+ 60°C	0.6	0.2	0.2	0.4	0.3	0.4	0.35	0.3	0.3	0.4	F
+ 21°C	0.8	0.2	0.8	1.0	0.8	1.0	1.05	1.1	0.6	1.3	NL
- 40°C	1.0	0.8	0.6	0.8	1.1	5.1	4.8	4.5	6.3	6.3	NL
- 10°C	0.7	0.9	1.6	0.7	0.4	0.5	1.0	1.5	1.7	1.7	NL
+ 60	0.8	0.9	0.8	0.7	0.6	0.3	0.55	0.8	0.4	0.3	NL
+ 21°C	0.7	0.4	0.5	0.6	0.8	0.6	0.5	0.4	0.5	0.5	UK
- 40°C	1.4	3.9	4.6	1.0	0.9	2.3	1.6	0.9	1.3	2.9	UK
- 10°C	0.4	1.1	2.5	0.5	1.3	0.9	0.65	0.4	0.9	0.8	UK
+ 60°C	0.6	1.1	0.8	0.4	0.7	1.0	0.6	0.2	0.6	0.4	UK
- 21°C	0.7	0.4	5.8	0.7	0.5	0.6	0.4	0.2	0.4	0.5	USA
- 40°C	0.2	0.4	3.3	0.3	1.0	1.5	2.4	4.3	1.7	2.1	USA
- 10°C	0.6	0.3	4.5	0.6	0.2	0.6	0.6	0.6	1.1	1.5	USA
+ 60°C	0.4	0.7	5.4	0.6	0.4	0.4	1.45	2.5	1.1	1.4	USA

*Units: bar (Ksi)

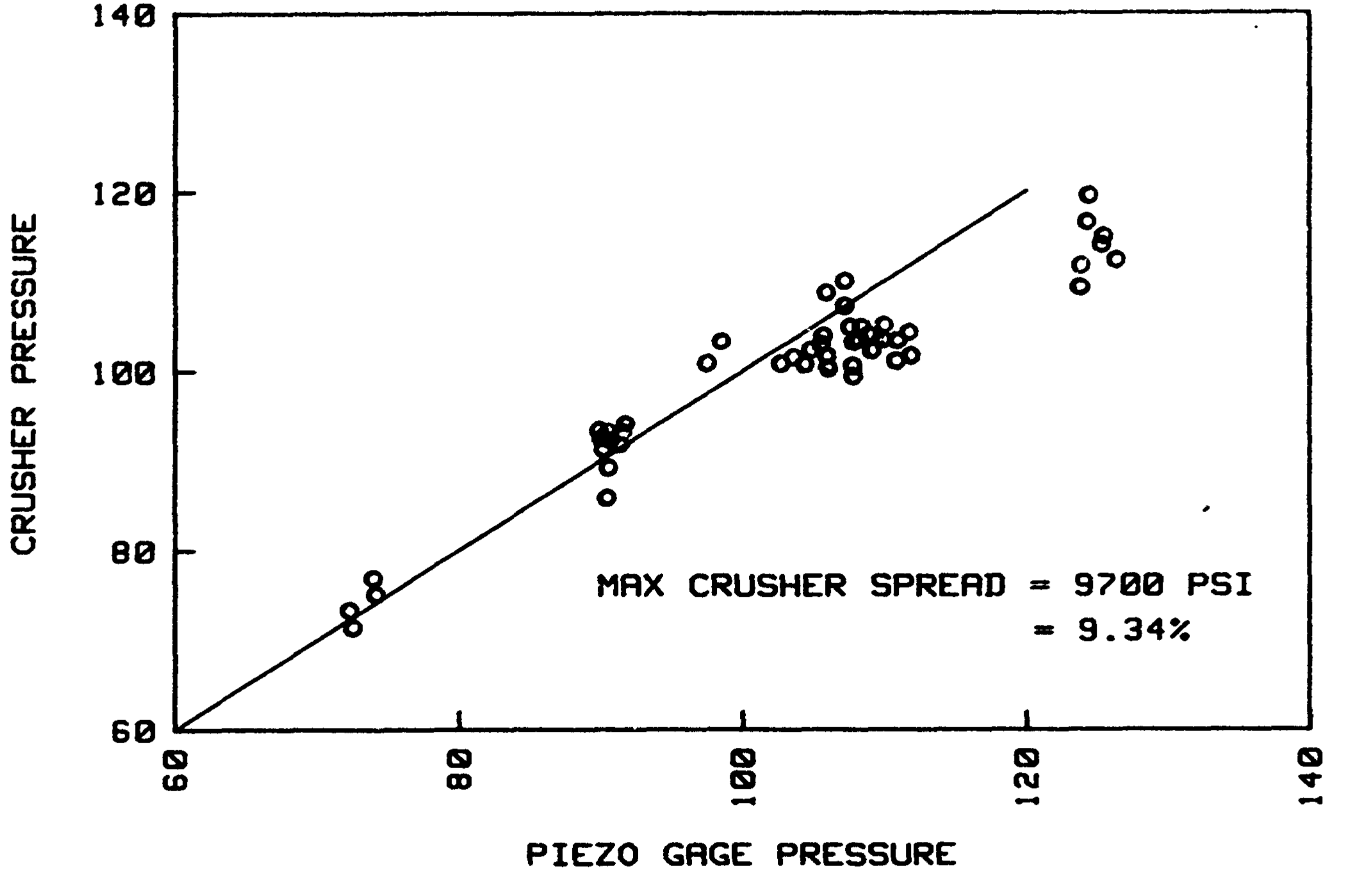

Figure 1. Crusher Pressure vs. Piezo Pressure of M-11 Gage

FINITE ELEMENT METHOD

The BRL relies heavily on its version of the SAAS II code [2, 3] and the accompanying grid generator written by the Rohm and Haas Company. The program also has the added feature of graphical output [4] which displays a deformed figure superimposed on the underformed figure.

A sketch of the M-11 gage is shown in Figure 2, from which the finite element grid in Figure 3 is derived. The loading scheme consists of pressurizing the entire exterior of the gage to 120 Ksi (828 MPa) including the sensing end of the piston. The crushing end of the piston is loaded with an opposing force to simulate the resistance of the copper sphere, the primary sensing element.

RESULTS

The result of the applied load is shown in Figure 4. The deformed grid's displacements are exaggerated 1000% for clarity. The most obvious deformation in the figure is the overlap of nodal points at the piston/bore interface. This is how the program indicates interference. The applied pressure has a direct path of action to the piston, thus clamping it before it has a chance to fully crush the sphere, as illustrated in Figure 4. However, due to the design tolerances, the bore and piston could have diameters such that the interference would not be as severe and the piston would be permitted its full travel, i.e., large bore/small piston. Also, the reverse could occur and result in a greater interference. The large spread of the data is attributed to this phenomenon. It is interesting to note that the gages used by the Federal Republic of Germany have similar piston/bore tolerances. However, at the assembly stage the pistons and bores are matched so that the diametral difference between them is nearly constant from gage to gage. Although this may be a solution to the M-11's problem, it could be very time consuming and costly to implement.

MODIFICATIONS

A more practical solution than piston/bore matching was to isolate the region of interference from the effects of the pressure. This was accomplished by shifting the path of pressure action to a region beyond the piston. It was determined that by shortening the piston and deepening the

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2. Sawyer, S. G., "BRLESC Finite Element Program for Axisymmetric Plane Strain, and Plane Stress, Orthotropic Solids with Temperature-Dependent Material Properties," BRL Report 2539, Ballistic Research Laboratories, Aberdeen Proving Ground, MD, March 1971 (AD #727702).

3. Jones, R. M. and Crose, J. G., "SAAS II Finite Element Stress Analysis of Axisymmetric Solids with Orthotropic, Temperature Dependent Material Properties," Aerospace Corporation, San Bernadino, CA, September 1968.

4. Zimmerman, K. L., "PLOTS - The plotting Subroutine Incorporated in the BRLESC Finite Element Computer Program," BRL Report 2209, August 1972.

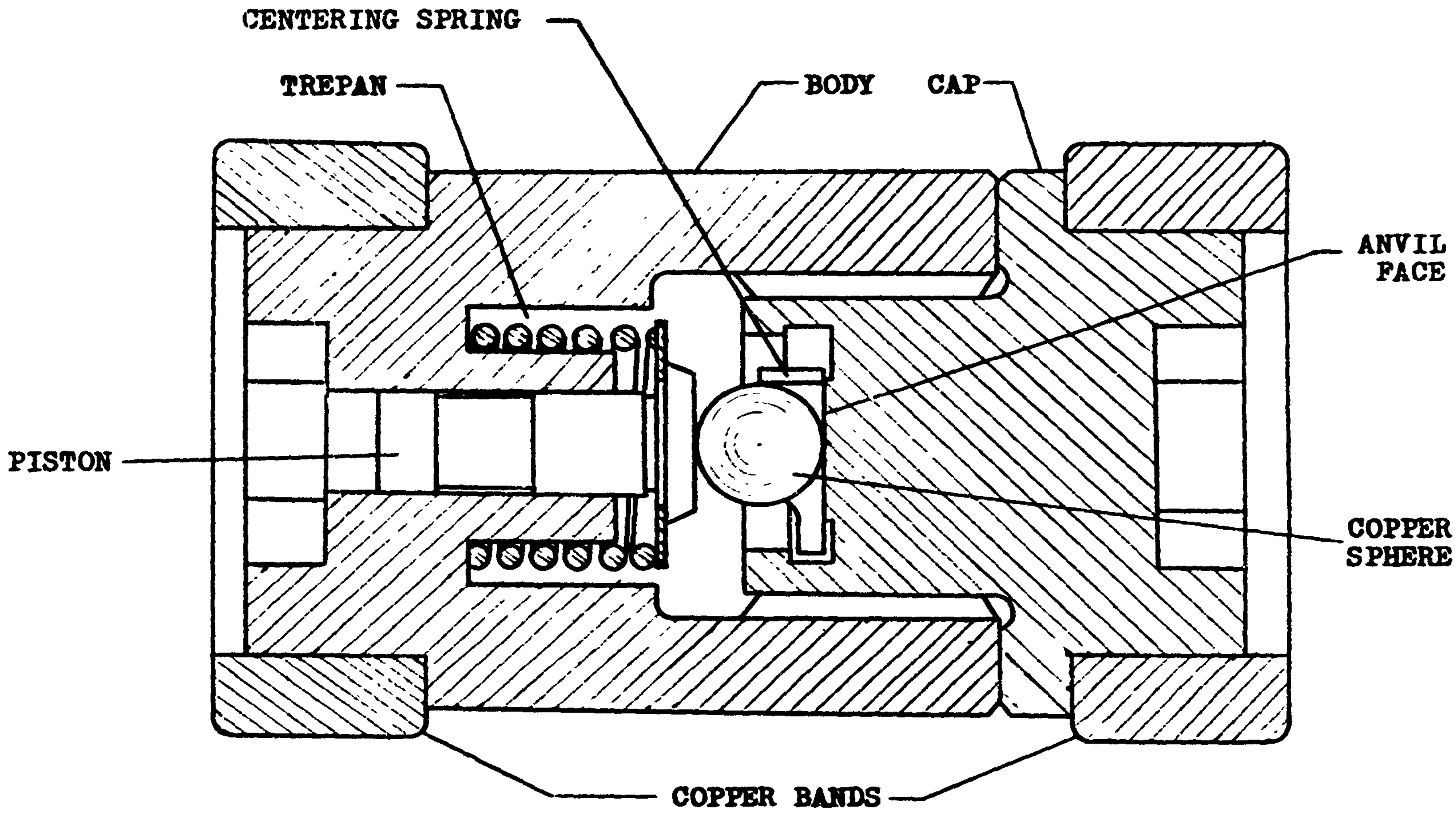

Figure 2. Assembly Sketch of M-11 Copper Crusher

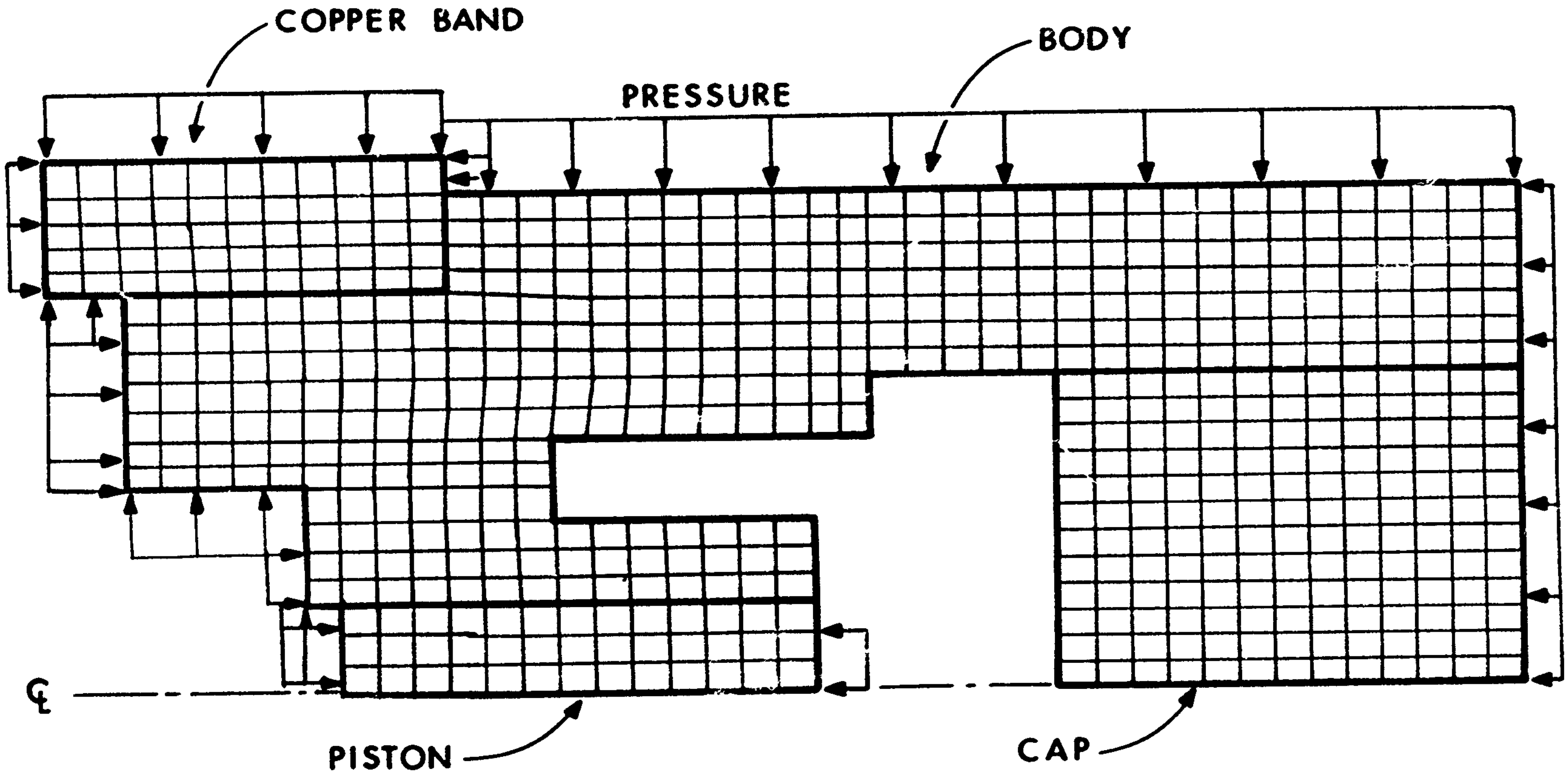

Figure 3. Finite Element Grid of Copper Crusher with Loading Scheme

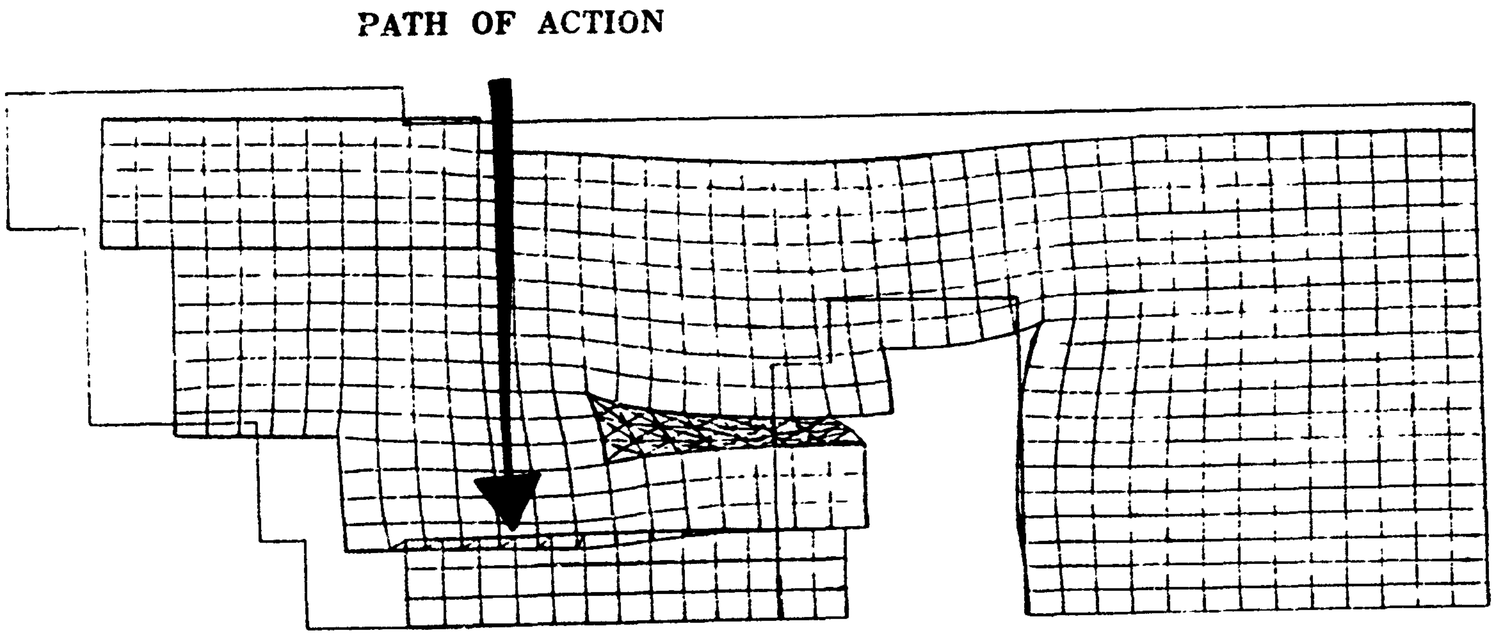

Figure 4. Deformed Finite Element Grid; Result of 80 Ksi (550 MPa)

trepan, the path of action is sufficiently shifted so as not to cause any interference at the bore (see Figure 5).

Several gages were fabricated with this modification and dynamically tested. Although the gages showed good agreement at high pressures, gas intrusion sufficiently damaged the inside of the gage so that repeated use was not possible. It was determined that the shortened piston left too much of the bore wall exposed to gas pressure. This pressure may have widened the bore at this point since there is no opposing pressure on the opposite side of the wall here. The additional clearance permitted the blowby of propellant gases into the gage. The dynamic tests were rerun with slightly longer pistons in the gages. The longer pistons would leave less bore wall exposed to pressure and, acting with the smaller bore wall further back, would create a better seal. This test produced the results shown in Figure 6 and demonstrates a marked improvement over the data shown in Figure 1.

DISCUSSION

It has been shown that the modified gage outperforms the present gage at 72°F (22°C) over the entire pressure range up to 120 Ksi (828 MPa). Although the gage's response was not simulated at high and low temperature extremes with the pressure, there is a high level of confidence that the gage will perform well in future hot and cold testing. A finite element analysis of the M-11 gage using a temperature boundary condition of -40°F (-40°C) alone did not significantly alter the piston/bore clearances. It is evident from the data in Table I that the combination of temperature and pressure extremes are harmful to the operation of the gage. By isolating much of the pressure effects from the piston/bore region the apparent sensitivity of the gage to temperature extremes is minimized.

REFERENCES

1. "Third NATO Crusher Gage Comparison Trials 1977, by Order of NATO AC 225 Panel IV," Meppen, FRG, October 1977.

2. Sawyer, S. G., "BRLESC Finite Element Program for Axisymmetric Plane Strain, and Plane Stress,Orthotropic Solids with Temperature-Dependent Material Properties," BRL Report 1539, Ballistic Research Laboratories, Aberdeen Proving Ground, MD, March 1971 (AD #727702).

3. Jones, R. M., Crose, J. G., "SAAS II Finite Element Stress Analysis of Axisymmetric Solids with Orthotropic, Temperature Dependent Material Properties," Aerospace Corporation, San Bernadina, CA, September 1968.

4. Zimmerman, K. L., "PLOTS - The Plotting Subroutine Incorporated in the BRLESC Finite Element Computer Program," BRL Report 2209, August 1972.

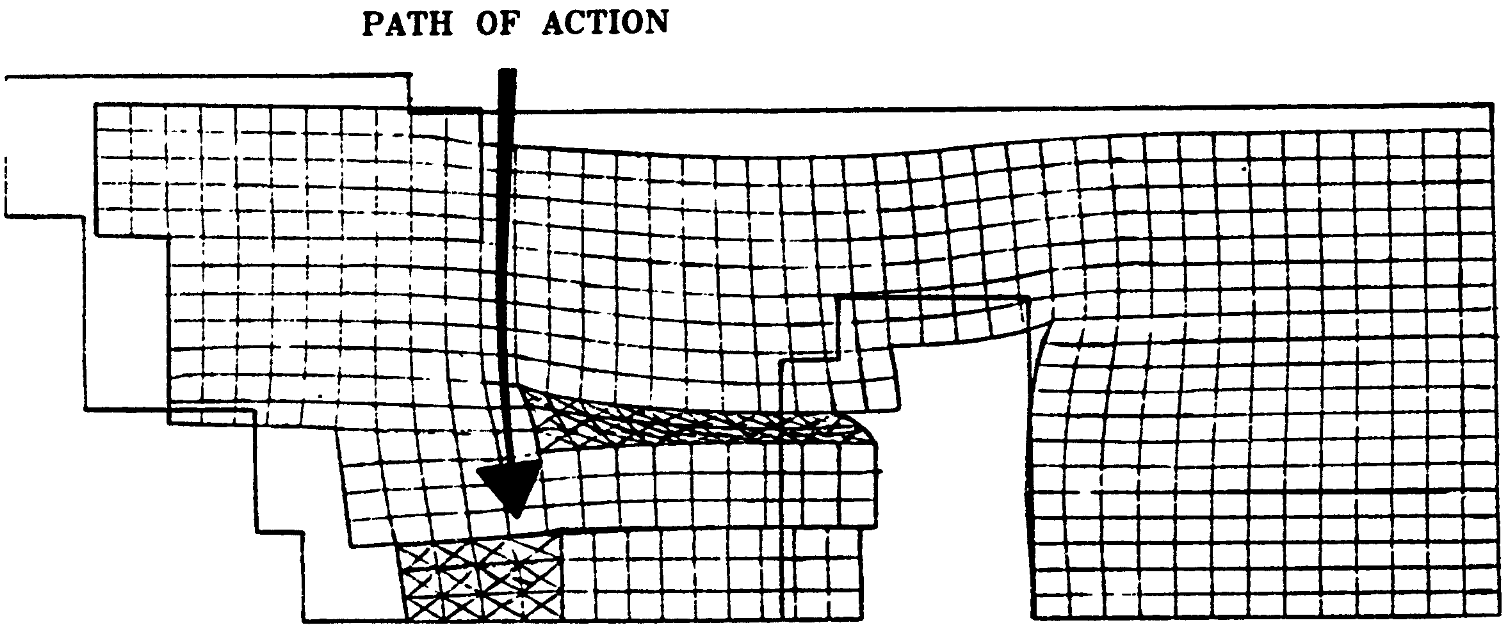

Figure 5. Result of 120 Ksi (838 MPa) Applied to M-11 Crusher Gage

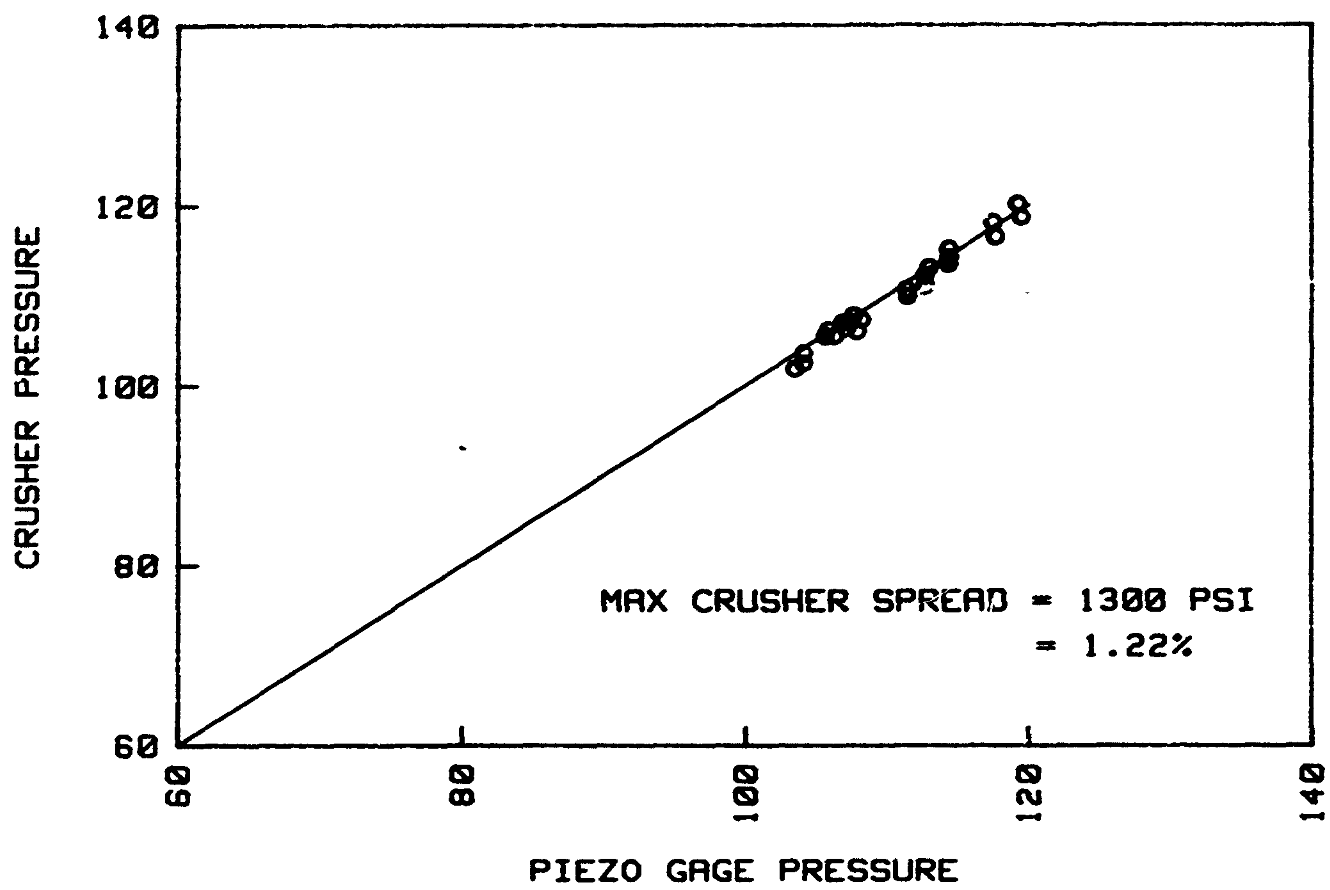

Figure 6. Crusher Pressure vs. Piezo Pressure of Improved M-11 Gage