SAE The Engineering Society For Advancing Mobility Land Sea Air and Space® INTERNATIONAL

400 Commonwealth Drive, Warrendale, PA 15096-0001

SURFACE VEHICLE RECOMMENDED PRACTICE

Submitted for recognition as an American National Standard

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SINGLE TOOTH GEAR BENDING FATIGUE TEST

1. ***Scope—***This SAE Recommended Practice defines the set-up and procedure for conducting the SAE Single Tooth Bending Fatigue Test. The details of the test fixture to be used (referred henceforth as "the test fixture" in this document) and gear test sample and the procedures for testing and analyzing the data are presented in this document.

1.1 Purpose—The objective of this document is to provide a means to evaluate the effects of material and process variables on the bending fatigue behavior of gears using the test fixture. The bending fatigue life of gear teeth is generally influenced by variations in such factors as geometry, material, microstructure, residual stress profile, surface finish, case depth, surface and core hardness.

This test serves as a screening tool to evaluate changes in one or more of these variables to enable optimization of the processing and design of gears.

2. ***References***

2.1 Applicable Publications—The following publications form a part of this specification to the extent specified herein. Unless otherwise specified, the latest issue of SAE publications shall apply.

2.1.1 SAE PUBLICATION—Available from SAE, 400 Commonwealth Drive, Warrendale, PA 15096-0001.

SAE J821042—Gear Single Tooth Bending Fatigue Test

2.1.2 ASTM PUBLICATION—Available from ASTM, 100 Barr Harbor Road, West Conshohocken, PA

STP-91—Staircase Method for Fatigue Experiments

2.1.3 AGMA PUBLICATION—Available from American Gear Manufacturer's Association, 1500 King Street, Suite 201, Alexandria VA 22314-2730.

AGMA 2001-B88—908-B89 Fundamental Ratio Factors and Calculation Methods for Involute Spur and Helical Gear Teeth

2.1.4 OTHER PUBLICATION

Statistical Design and Analysis of Engineering Experiments, Lipson and Sheth, "Fatigue Experiments," pp. 262-275.

3. Test Specimen—The test uses a specific gear as a test specimen to account for the complex nature of bending and residual stress in a gear after processing and during loading. A straight cut 6-pitch, 34-tooth, 20-degree pressure angle spur gear with no tip relief is the recommended test sample (Figures 1A and 1B). Other tooth sizes and profiles are acceptable, depending on specific objectives of the test.

4. Test Fixture

4.1 The test fixture design was evaluated and selected by the SAE ISTC Division 33 Gear Metallurgy Committee and validated by a round robin gear test program. The results of the test machine validation are reported in SAE Publication 821042 (Reference 2.1.1) using a carburized and shot peened SAE 8620 steel gear. Figures 2 and 3 shown the overall views of the fixture set-up. Figures 4 through 13 show the detail drawings of the components of the test fixture. The fixture consists of a base (Figure 4), an upper load anvil (Figure 5), a lower support anvil (Figure 6), and a mandrel or mounting shaft (Figure 7). The fixture is adaptable to a variety of hydraulic cyclic testing machines when positioned between the load platens, provided the load is applied to the spherical seat located in the top anvil (Figures 2 and 3).

4.2 The replaceable upper anvil insert (Figure 8) (not crowned) loads the test gear at the tooth tip. The replaceable lower anvil insert (Figure 9) (not crowned) resists the load applied through the upper anvil and prevents sample rotation by contacting a support tooth near the base circle. The upper anvil (Figure 5) is mounted on the loading arm (Figure 10) as shown in Figure 11. The fixture base, load anvil and support anvil are aligned by a common shaft (Figure 7). The test gear is mounted on the shaft supported by roller bearings at the ends. The bearing supports are shown in Figure 13. The gear and load anvil rotate in an arc about the gear axis, keeping a single line of contact across the gear tooth during loading. Load is applied to the fixture through a large ball bearing (Figures 2 and 3) to eliminate misalignment and to keep applied force in line with the loading and support anvils. The complete test assembly is shown in Figure 13.

5. Test Procedure

5.1 Gear Preparation—One gear tooth must be removed prior to testing the gear to provide clearance for the support anvil in the tooth root. This is accomplished by carefully grinding away one tooth (Figure 3) taking care not to heat the gear above the tempering temperature. An alternate method is to remove the tooth prior to heat treatment.

5.2 Fixture Calibration—It is recommended that one test gear be strain gaged and used to periodically verify the consistency of the test fixture. Wear on the anvil and shaft surfaces will change the loading on the gear tooth and subsequently the root stress. A procedure for preparing a calibration gear using contact strain gages is given in Appendix A. All components are replaceable items. The recommended calibration procedure is estimated to provide a strain measurement precision of ±10%.

5.3 Test Assembly—The test gear is first mounted on the shaft, then the support anvil is placed against one tooth root to prevent the gear from rotating. The load anvil is mounted on the same shaft as the gear and rotates in an arc around the gear axis. The load anvil contacts a tooth at the end of the active profile across the entire face of the tooth. Care must be taken to avoid corner loading or uneven contract across the face of the test tooth. Figure 13 shows the support anvil contacting the tooth in the root and the load anvil contacting the tested tooth at the tip. This ensures that a tensile bending stress is applied to the root of the test tooth. Support teeth are not used as tip loaded fatigue test specimens in subsequent tests. Suggested tooth loading scheme is shown in the gear depicted in Figure 14.

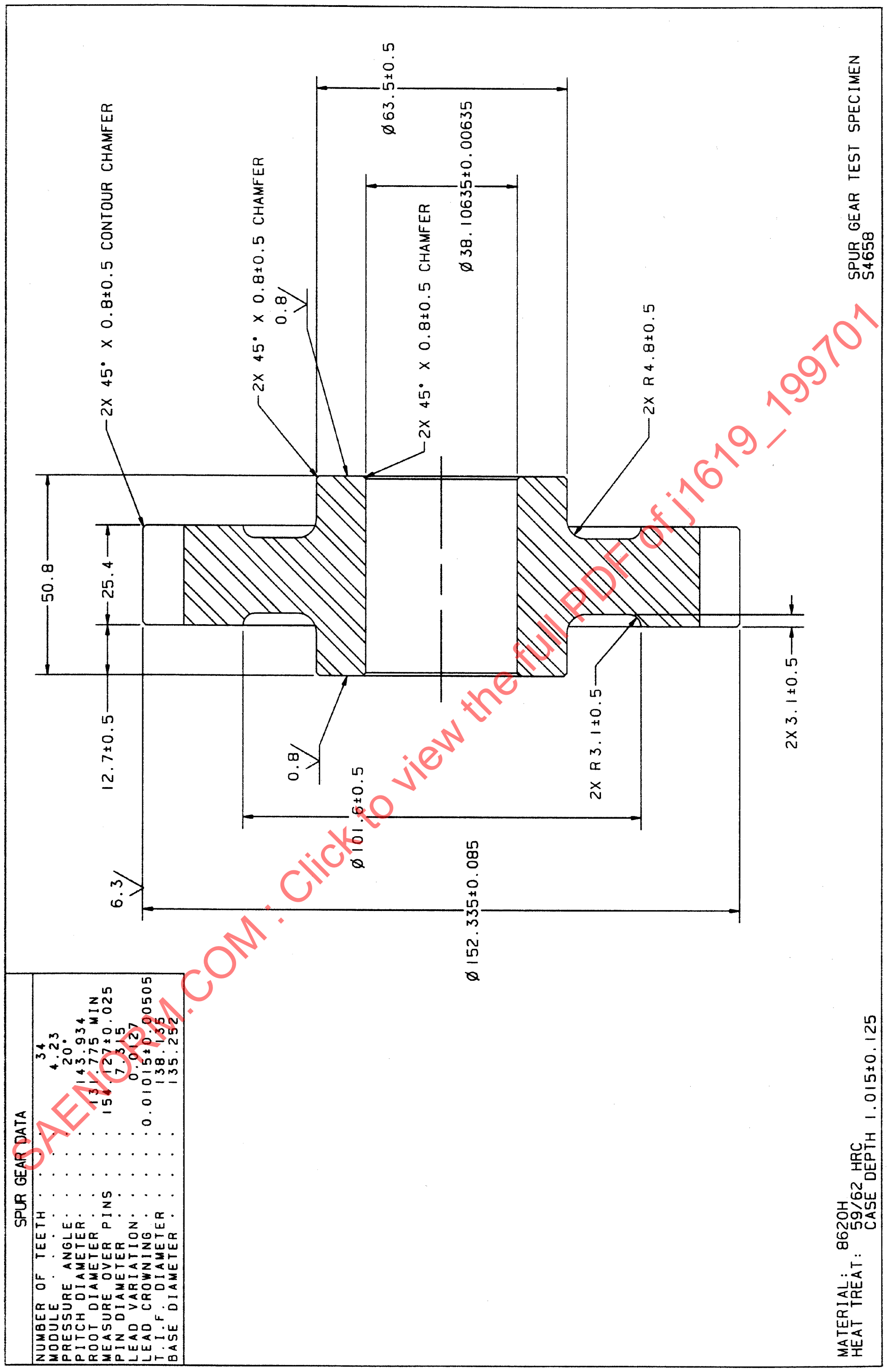

FIGURE 1A—SPUR GEAR TEST SPECIMEN

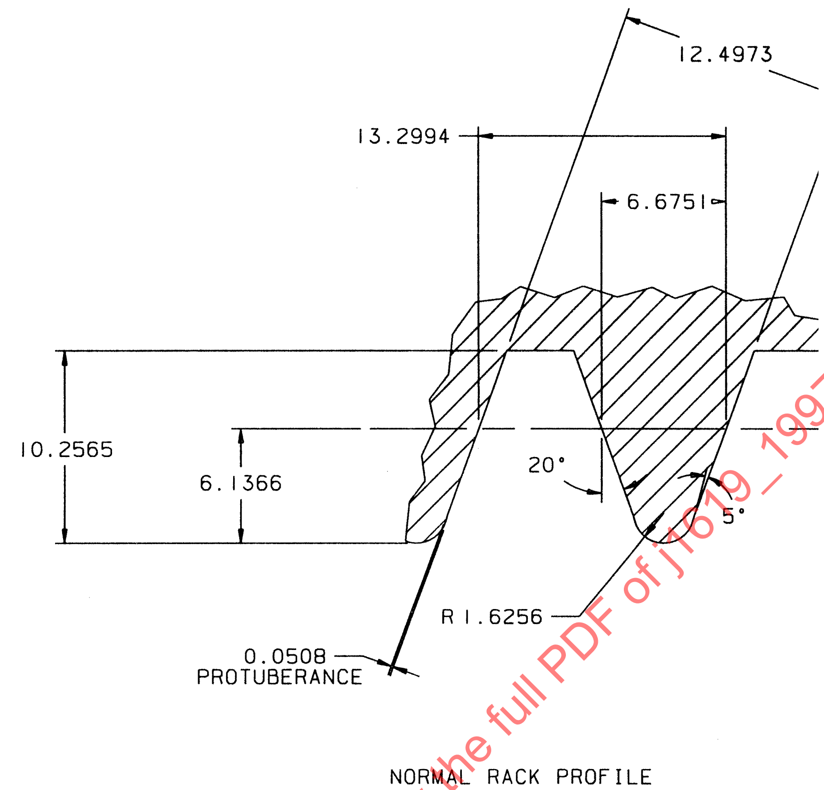

FIGURE 1B—NORMAL RACK PROFILE

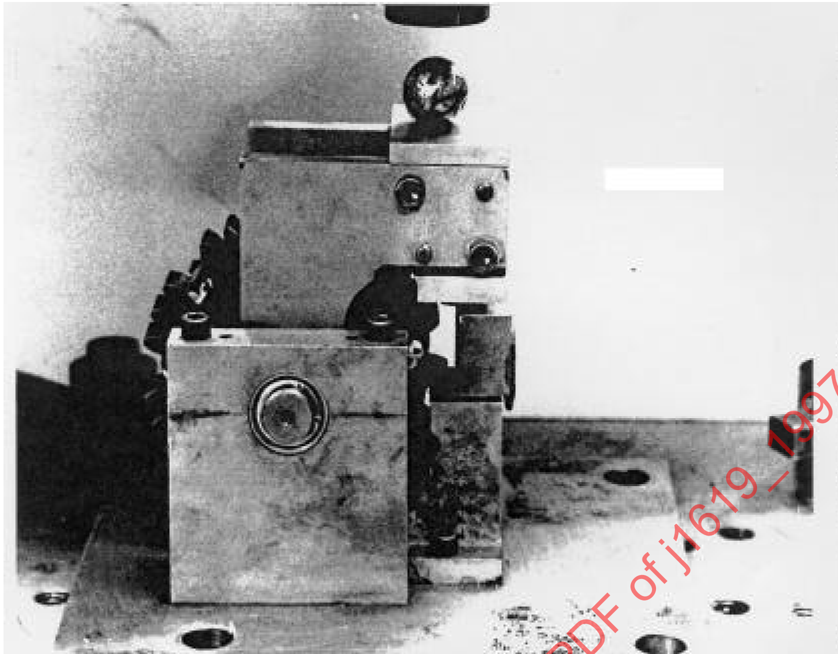

FIGURE 2—TEST FIXTURE ASSEMBLY

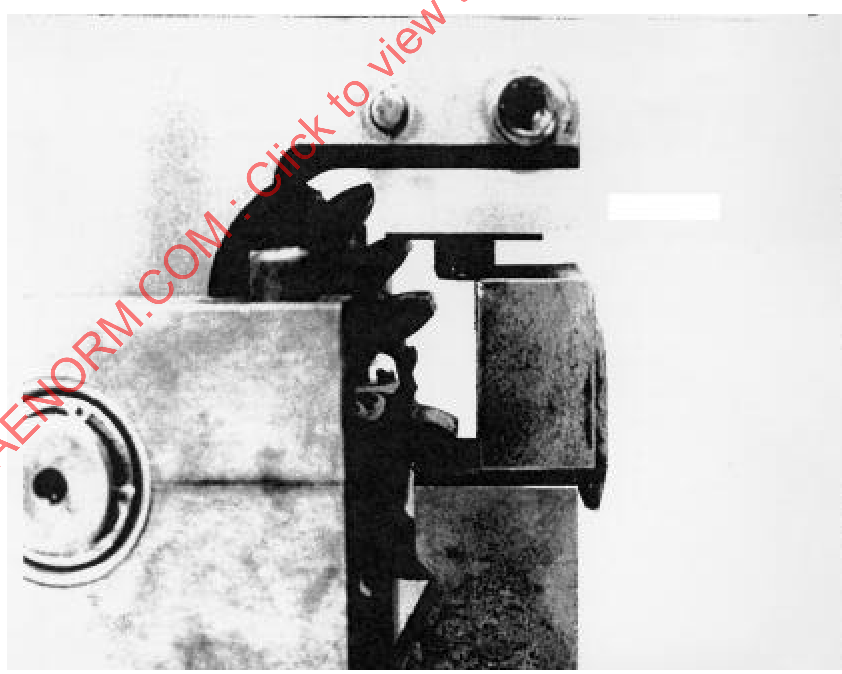

FIGURE 3—CLOSE-UP OF TEST GEAR SET-UP

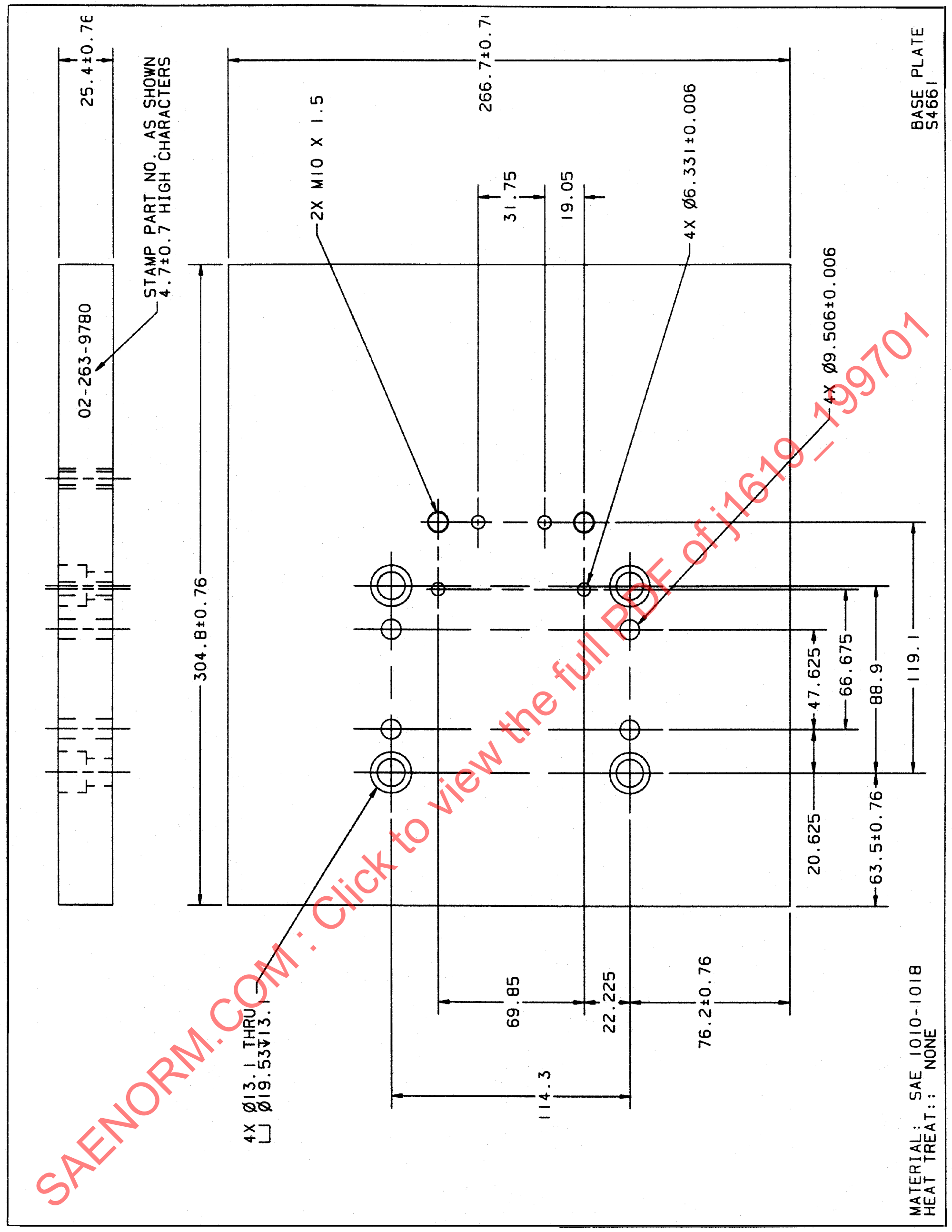

FIGURE 4—BASE PLATE

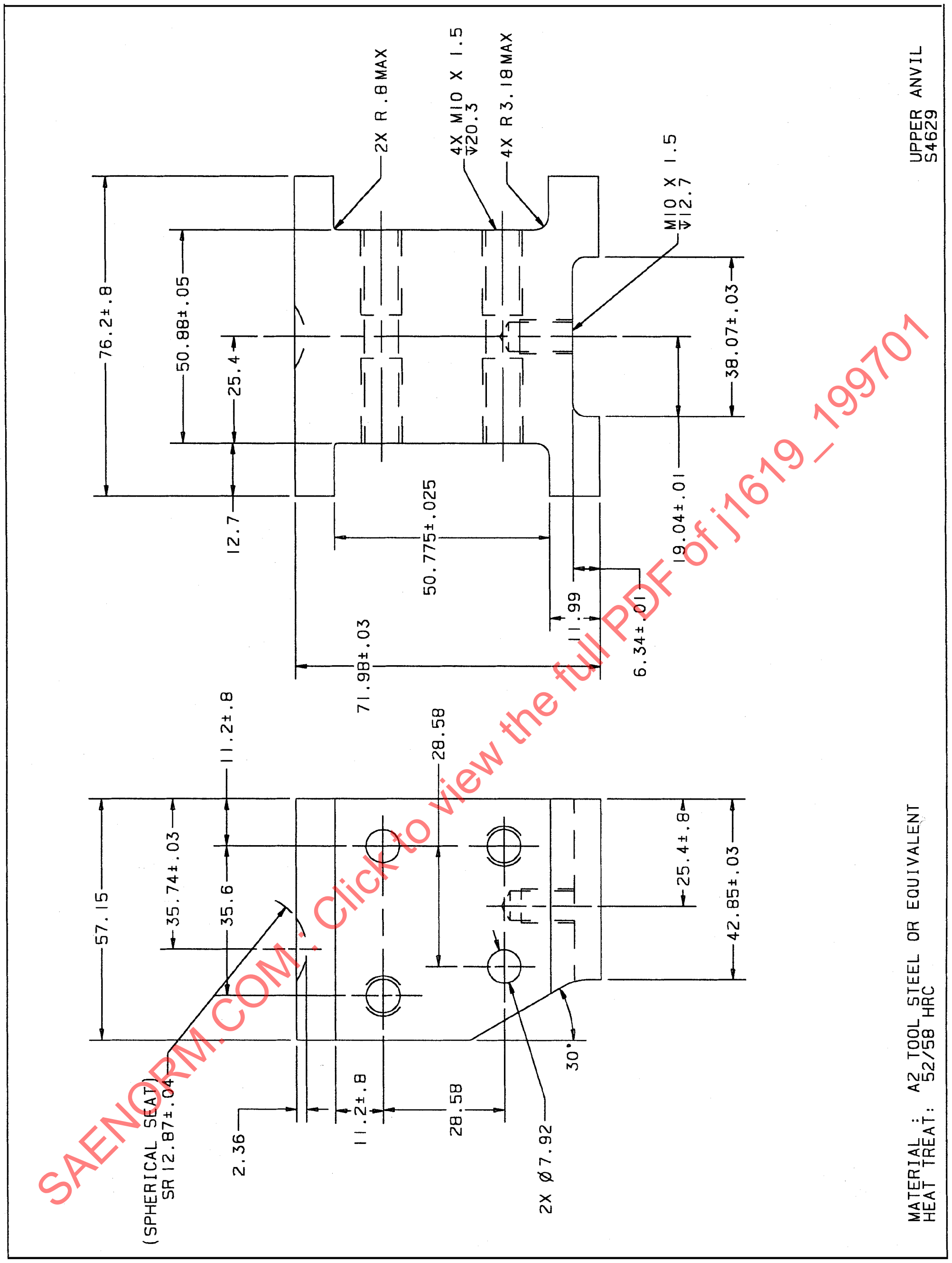

FIGURE 5—UPPER ANVIL

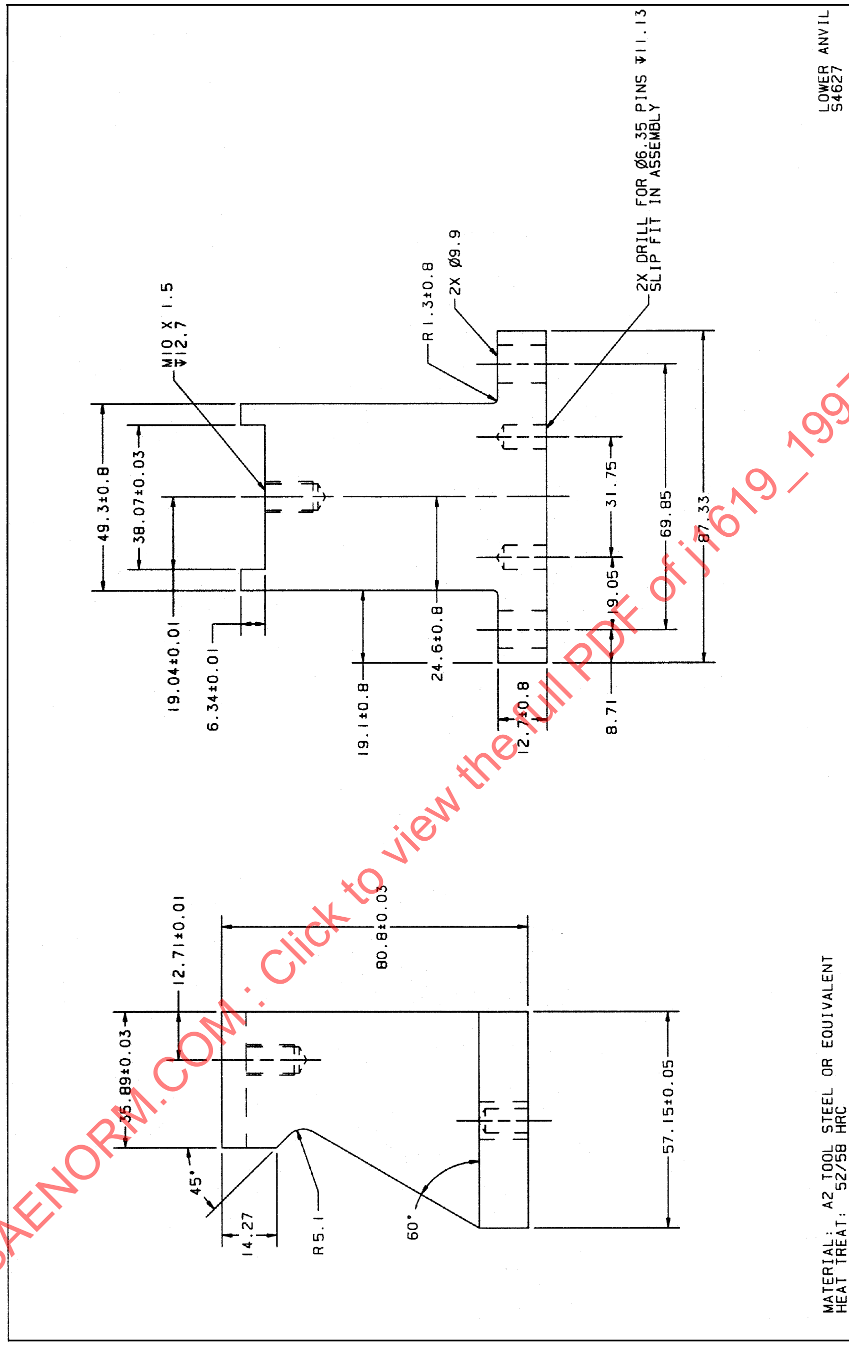

FIGURE 6—LOWER ANVIL

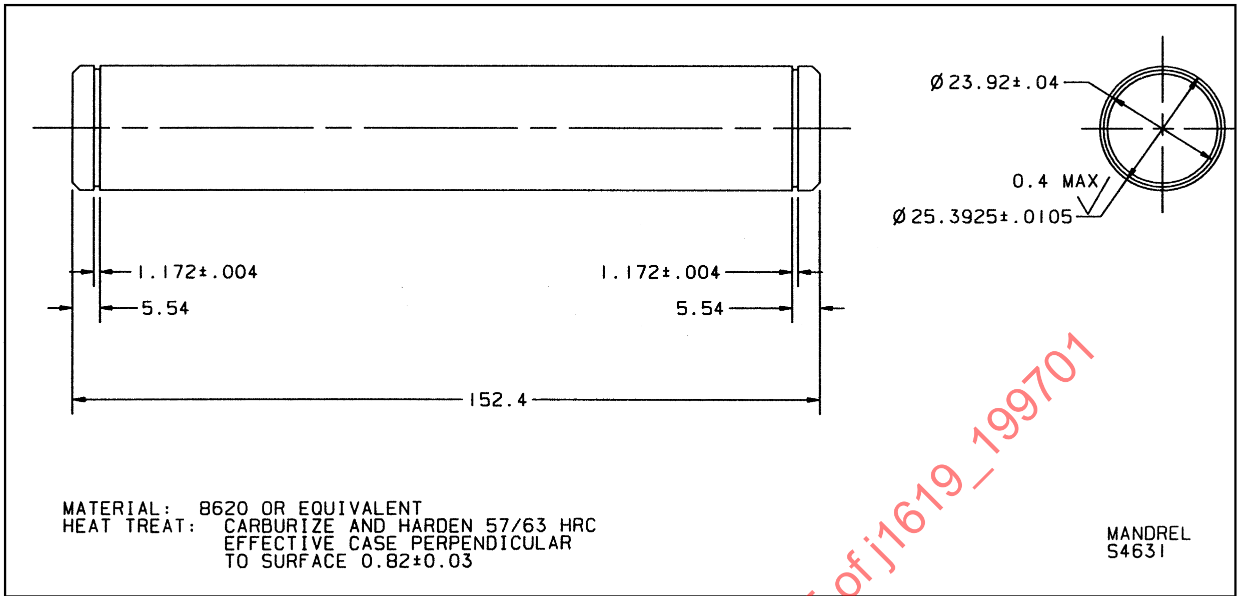

FIGURE 7—MANDREL

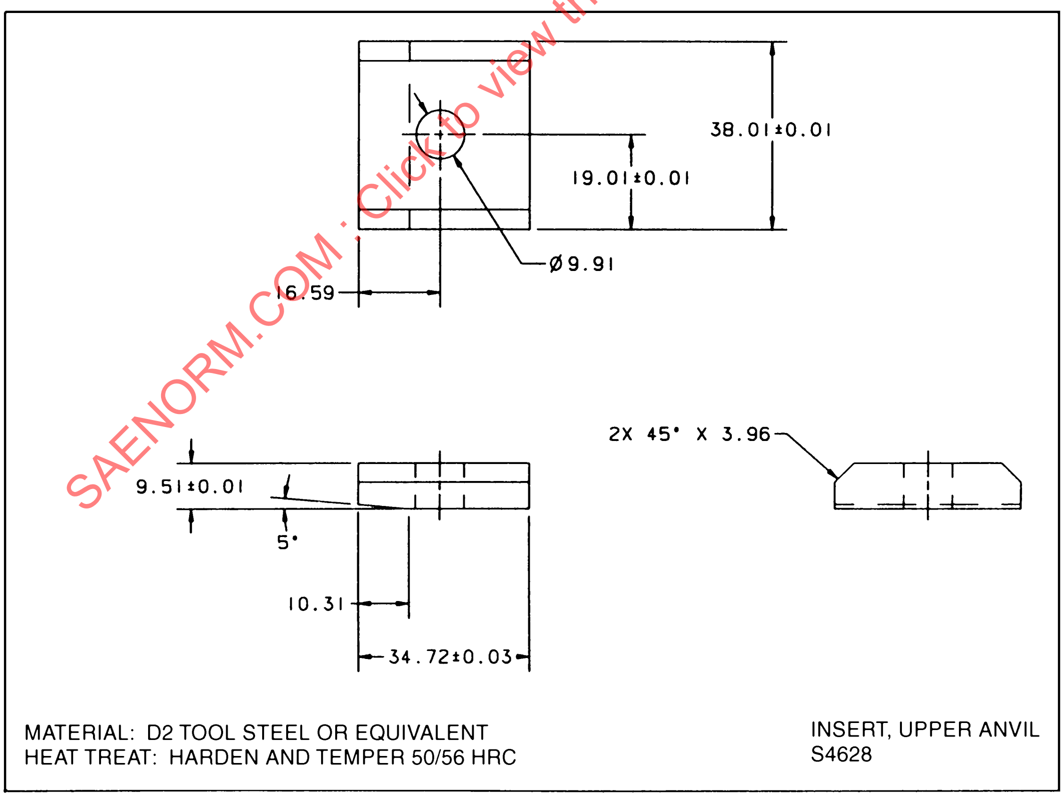

FIGURE 8—INSERT, UPPER ANVIL

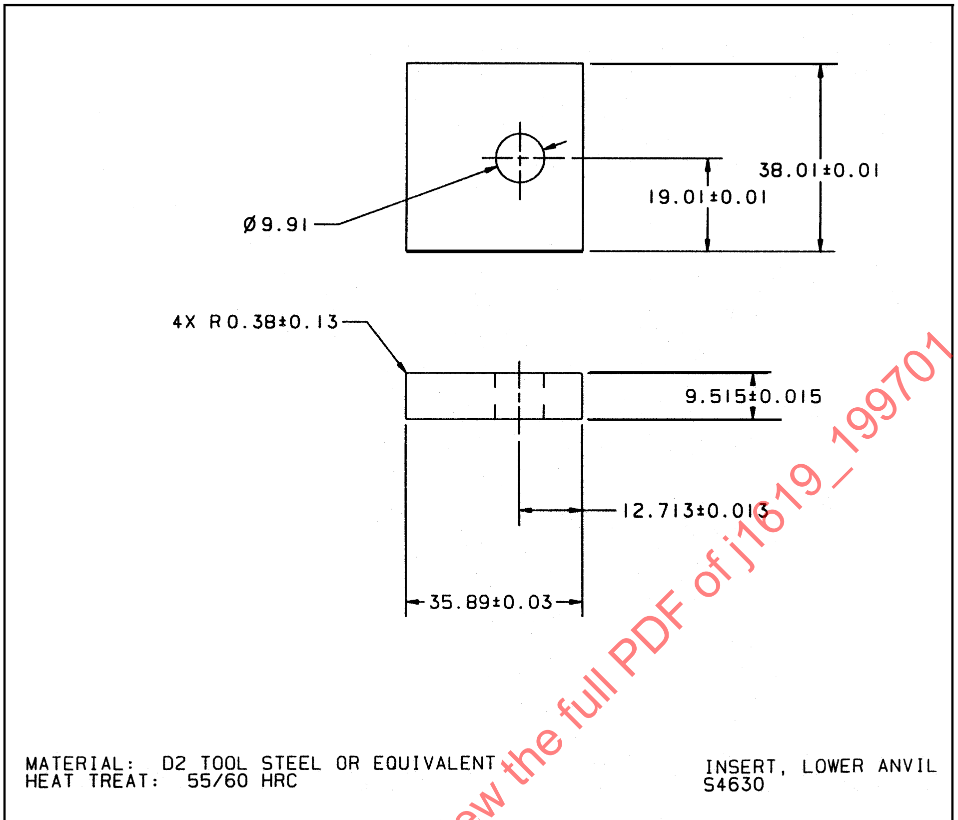

FIGURE 9—INSERT, LOWER ANVIL

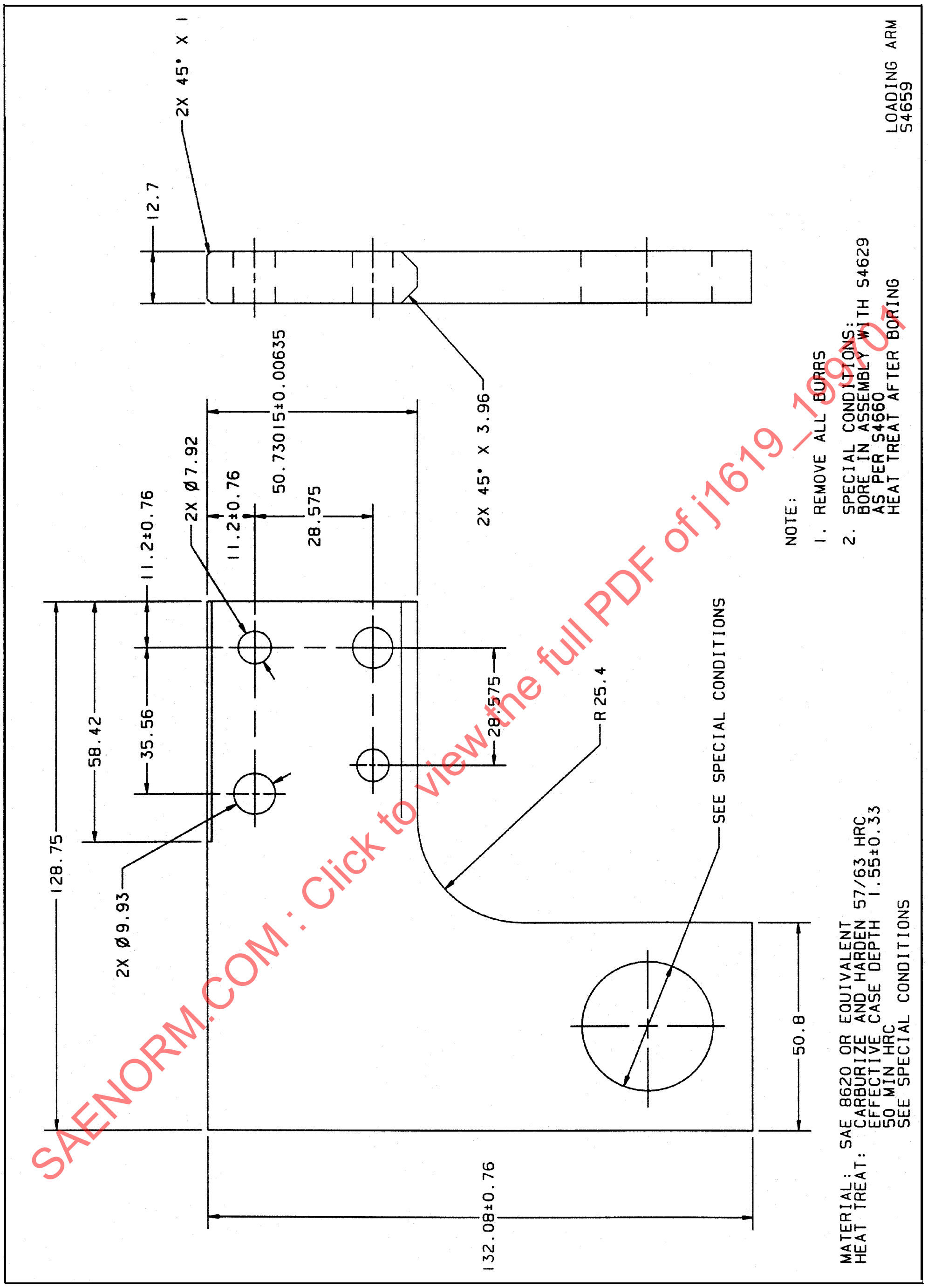

FIGURE 10—LOADING ARM

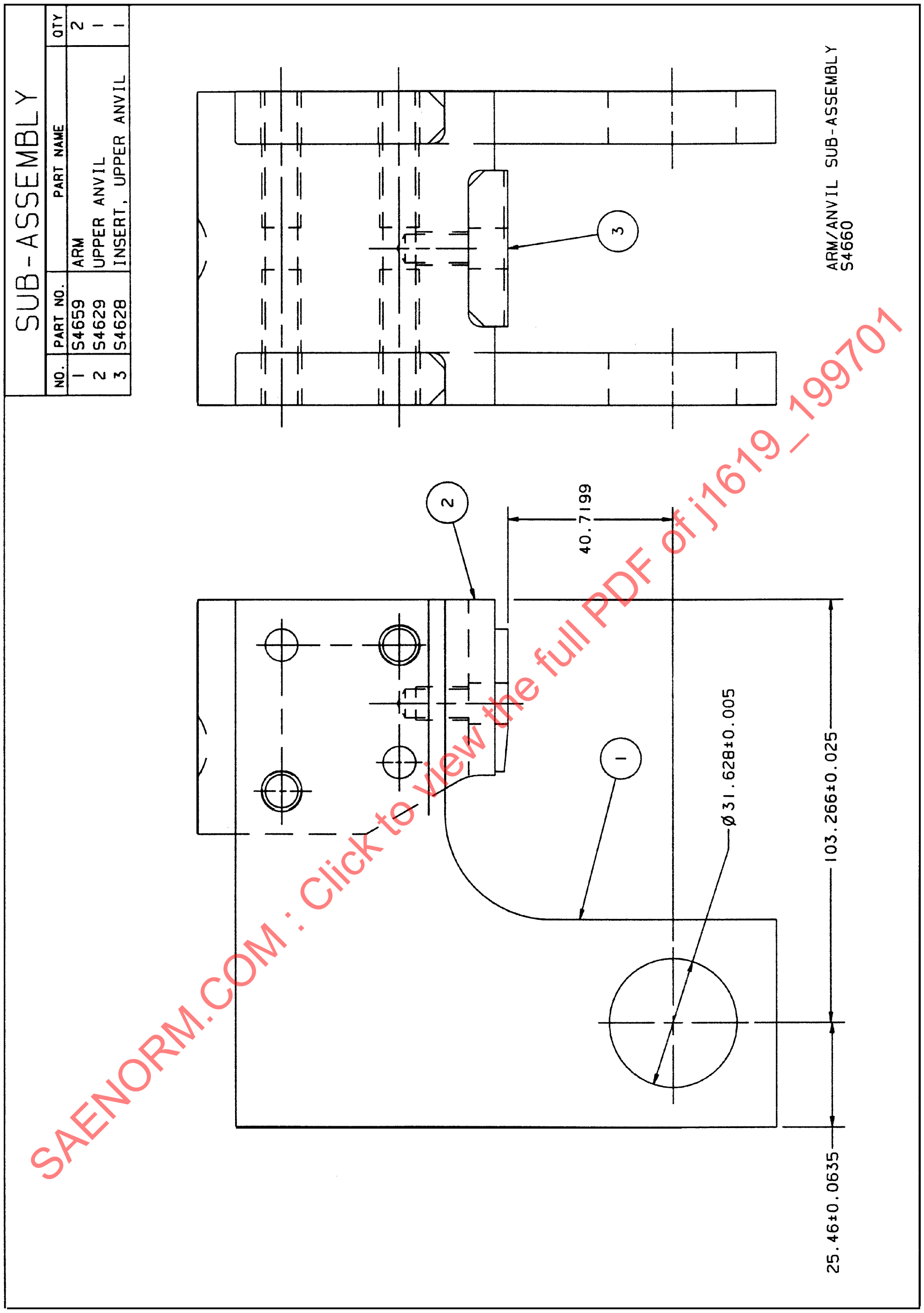

FIGURE 11—ARM/ANVIL SUB-ASSEMBLY

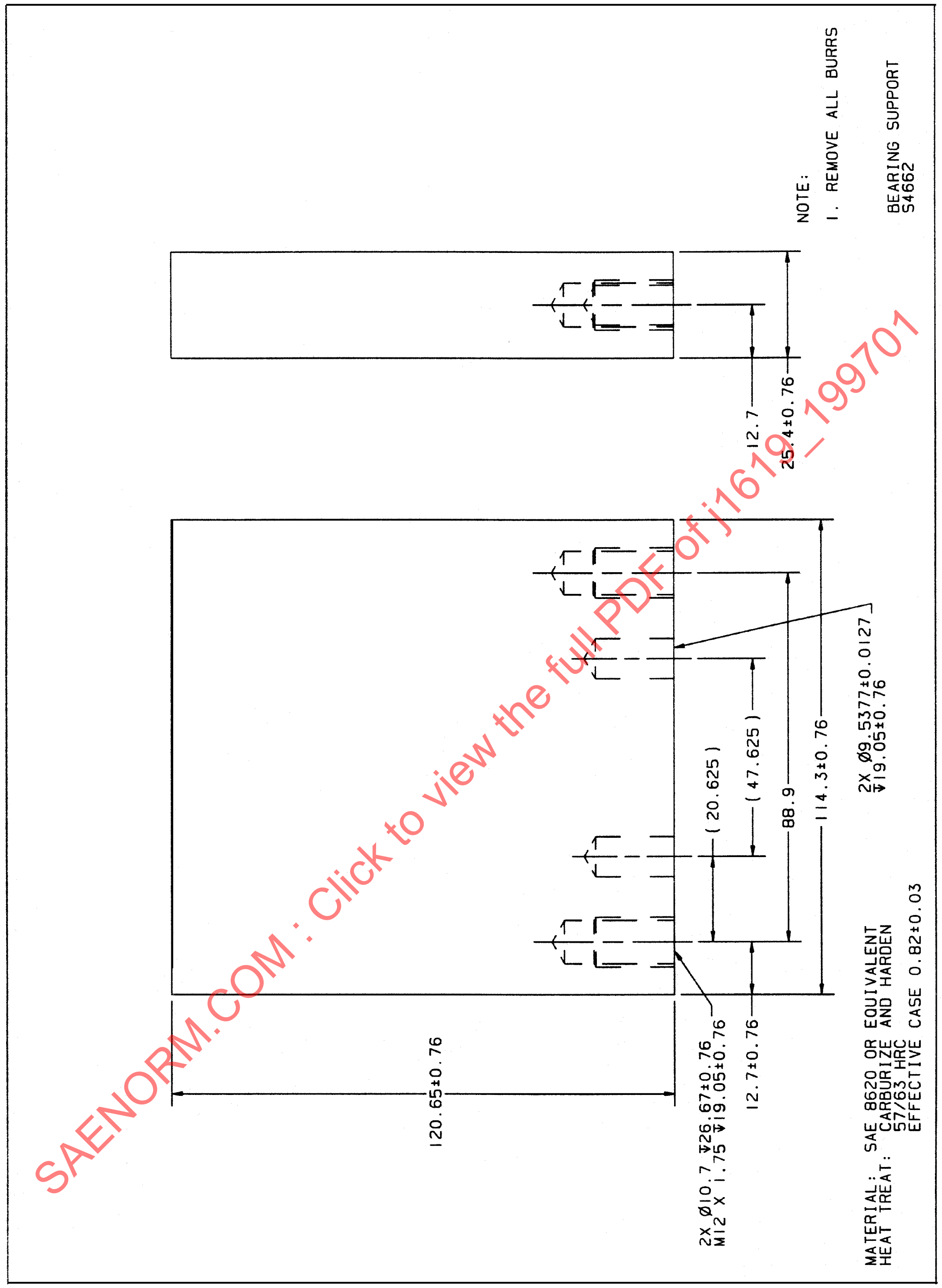

FIGURE 12—BEARING SUPPORT

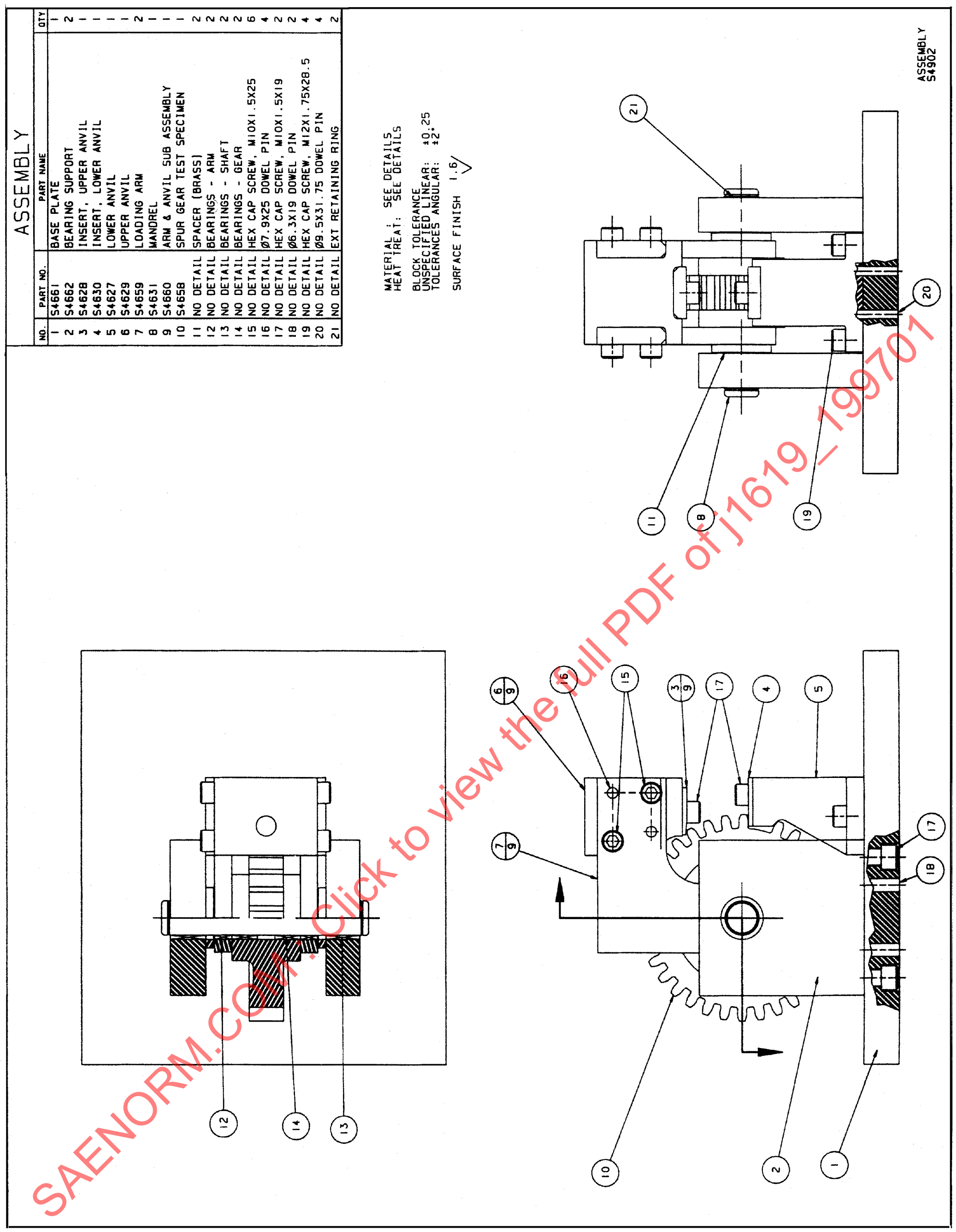

FIGURE 13—ASSEMBLY

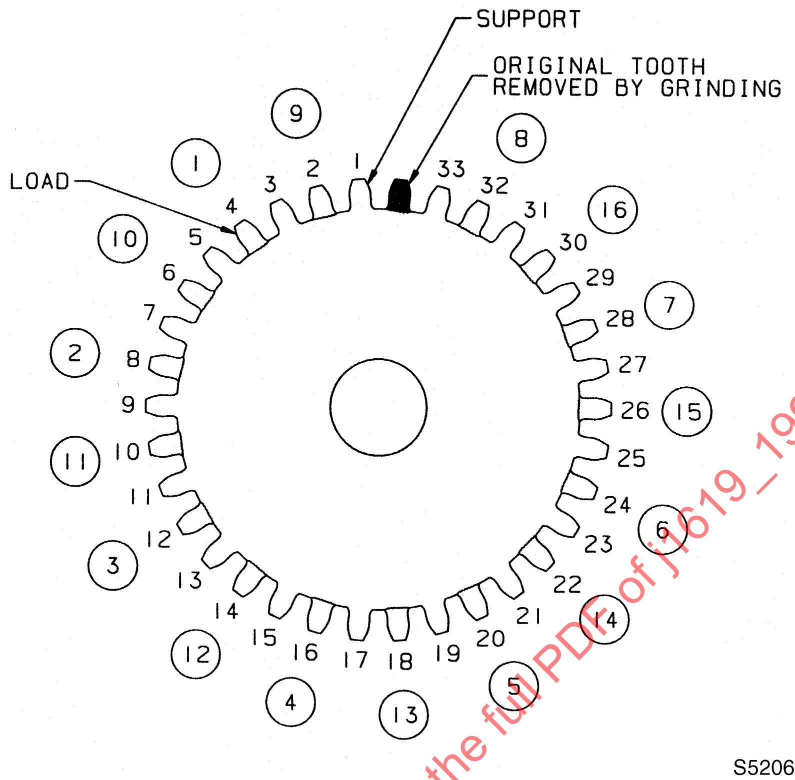

FIGURE 14—DIAGRAM OF GEAR SHOWING USABLE TEETH FOR TESTING

5.4 Loading—When the load anvil is in contact with the tooth root, the test tooth is loaded by having the loading device make contact through the spherical seat located in the upper load anvil (see Figure 5). Single tooth bending fatigue tests are conducted using a constant amplitude cyclic load of 20 to 30 Hz.

5.5 Testing—A cyclic load pattern with a minimum load magnitude of 10% of the maximum load (R = minimum load/maximum load = 0.1) is recommended to keep the load anvil in contact with the test tooth and avoid shock loading. Gear teeth are tested until complete tooth fracture is achieved and the load and cycles to fracture are recorded for each tooth. The base of the test fixture is operated on a film of oil to eliminate the transfer of side loads into the tooth and loading device.

5.6 Analysis of Results—The S-N (Stress versus Cycles) curve is composed of two lines. The finite part of the plot is determined by testing at a minimum of three distinct stress levels. The endurance limit or infinite part of the curve is determined using the Stair Case method described in ASTM STP-91 (Reference 2.1.2). The two curves meet at a point commonly called the "knee." A method for determining the range of endurance limits based on statistical methods is described in Statistical Design and Analysis of Engineering Experiments, Lipson and Sheth, "Fatigue Experiments," pp. 262-275 (Reference 2.1.4). The test provides a guideline for the selection of loads in the finite portion of the curve. A life of 10 million cycles will determine a run-out; any shorter life is a failure. Appendix B provides further details of testing scheme and analysis.

5.7 Gear Stress Estimation—Formulas to calculate the bending stress in the roots of gear teeth are given in AGMA 2001-B88 and 908-B89 (Reference 2.1.3). The load angle of the test fixture is used to calculate the bending stress in gears. To enable a reliable comparison of results between tests on a given gear geometry, some formulas must be applied consistently for stress calculations.

6. ***Report—***Report results in the form of an endurance curve of stress versus log number of cycles to failure in a semi-log plot with the log cycles to failure on the X-axis. Important parameters to be reported along with the test results are:

a. Gear Material—Steel grade, chemistry, cleanliness
b. Case Depth—Surface carbon if applicable
c. Carbon gradient and surface carbon
d. Case and Core Hardness Data—Hardness gradient
e. Grain Size
f. Microstructural—Percent retained austenite, presence of any oxides
g. Calibration Data
h. Finishing method after heat treatment (e.g., shot-peening characterization, details, and grinding process as applicable)
i. Residual stress profile as applicable

PREPARED BY SAE IRON AND STEEL TECHNICAL COMMITTEE DIVISION 33—
GEAR METALLURGY