TECHNICAL EVALUATION REPORT

EVALUATION OF McGUIRE UNITS 1 AND 2

UNDERVOLTAGE TRIP ATTACHMENT FAILURES

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FOREWORD

This Technical Evaluation Report was prepared by Franklin Research Center under a contract with the U.S. Nuclear Regulatory Commission (Office of Nuclear Reactor Regulation, Division of Operating Reactors) for technical assistance in support of NRC operating reactor licensing actions. The technical evaluation was conducted in accordance with criteria established by the NRC.

1. INTRODUCTION

This report contains the findings of Franklin Research Center (FRC) concerning the evaluation of failures of undervoltage trip attachments (UVTA) associated with Westinghouse DS-416 reactor trip circuit breakers (RCTBs) from McGuire Units 1 and 2.

The scope of work for this effort includes the evaluation of:

1. the interaction between the UVTA and the associated circuit breaker,
2. the failure modes (both those recognized by the Licensee and vendor and those determined by FRC during the evaluation),
3. newly prescribed test methodology for determining correct mating between the UVTA and the circuit breaker and for determining the adequacy of critical clearances between components of the UVTA,
4. modifications made by the vendor to prevent failures, and
5. evaluation of baseline test data taken on McGuire RTCBs.

2. DESCRIPTION OF UVTA OPERATION

Figure 1 shows a cutaway view of the UVTA for the DS-416 RTCB. Figure 2 shows the interaction of the UVTA with the trip pin of the RTCB. When the RTCB opens, an arm connected to the pole shaft of the RTCB causes the UVTA reset lever to reset the UVTA by causing the roller bracket to rotate to the position with the roller bearing under the reset lever bracket and the moving core to be fully inserted into the coil. If the coil is energized at this point, the UVTA will remain latched when the circuit breaker is closed. When the coil of the UVTA is deenergized, the roller bracket spring causes the roller bearing to move out from under the reset lever, allowing the reset lever spring to lift the trip tab of the UVTA, which strikes the trip pin on the circuit breaker trip bar.

If the UVTA is not energized when the RTCB is closed, the roller bracket rotates immediately, allowing the trip tab on the reset bracket to strike the trip pin on the RTCB trip bar, which causes the circuit breaker to open immediately.

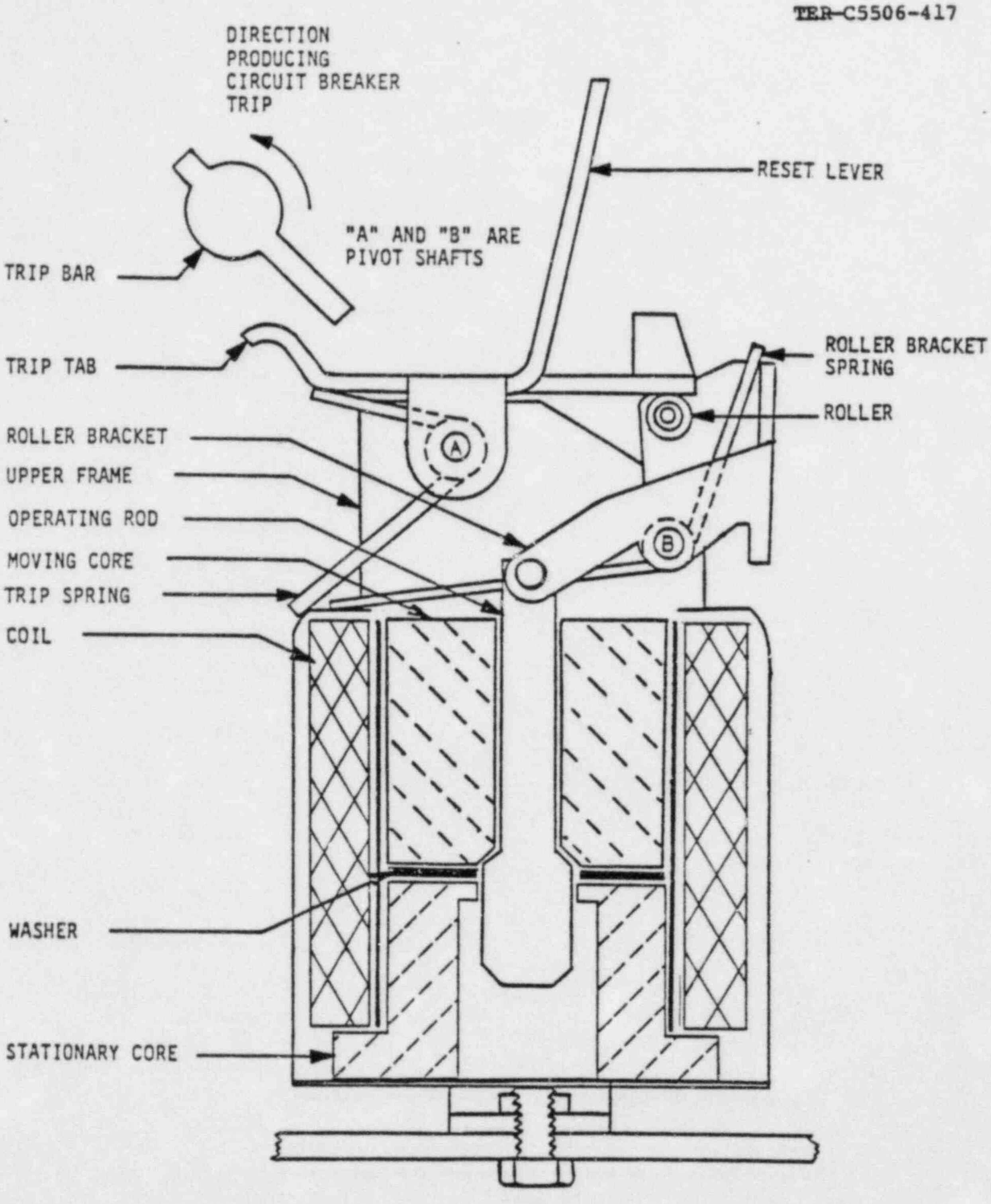

Figure 1. DS-416 Undervoltage Trip Attachment

Note: Portion of reset arm and roller bracket arm not shown. The parts not shown cause mechanical resetting of the device when the circuit breaker opens.

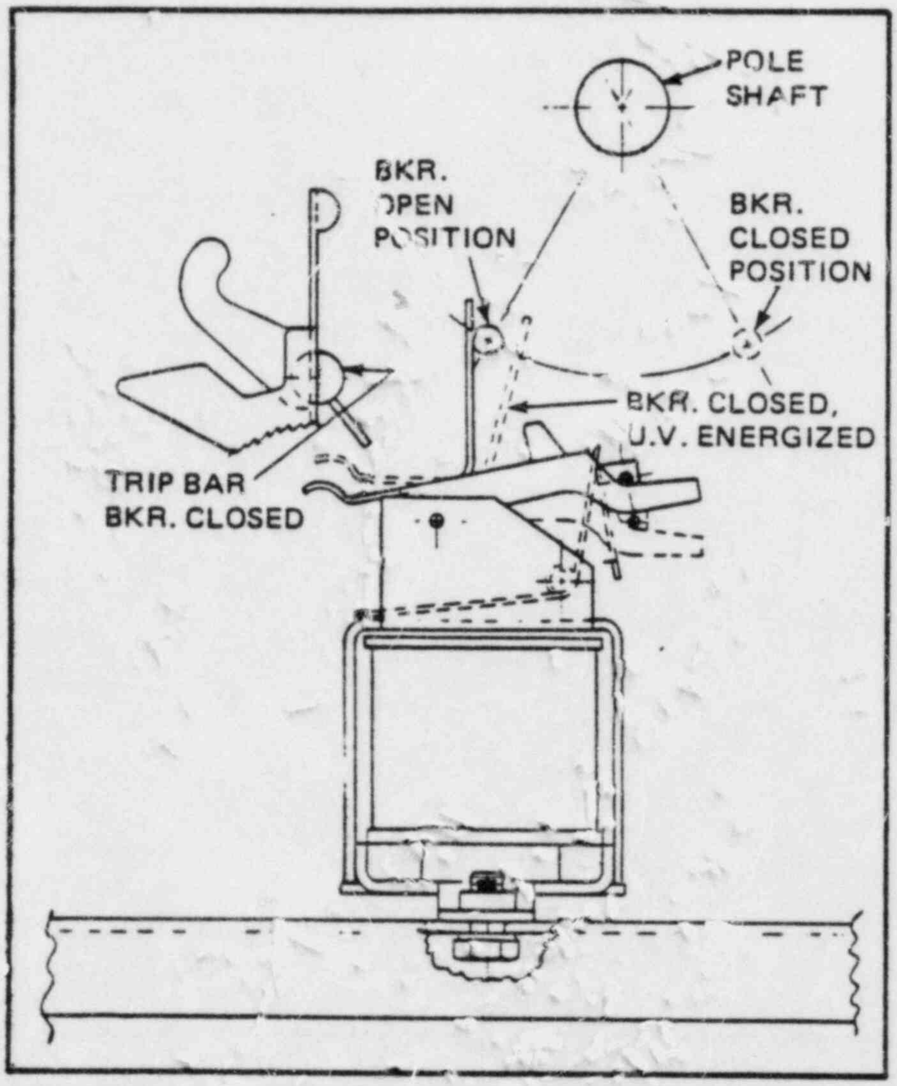

Figure 2. Undervoltage Trip Device Operation

3. EVALUATION OF THE INTERACTION BETWEEN THE UVTA AND THE CIRCUIT BREAKER

To evaluate circuit breaker and UVTA interaction, Mr. G. Toman and Mr. J. Stone of FRC traveled to McGuire Nuclear Station on May 13, 1983 to view the RTCB installation, to watch a new UVTA and several failure-prone UVTAs in operation on a circuit breaker, and to discuss the past failures and corrective action with Duke Power Company personnel.

3.1 DISCUSSION OF FAILURES

The following paragraphs describe the failures of DS-416 UVTAs that occurred during testing and evaluation by Westinghouse and Duke between mid-March 1983 and May 13, 1983.

The first failure mode was attributed to inadequate clearances between components of the UVTA. Two internal clearance problems were found: inadequate clearance between the roller bracket and the moving core (see Figure 1 for nomenclature and Figure 3 for photograph of components with clearance problems), and inadequate clearance between the roller bracket and the spacer bushing on the roller bracket pivot pin.

The second failure mode involved improper clearance of the UVTA trip tab with respect to the circuit breaker trip pin on the rotating trip bar. The third failure mode involved the retaining clips of the pivot shafts that could walk off the shaft ends, allowing the shafts to drop out of the frame and causing the device to jam.

The corrective action recommended by Westinghouse for the third failure mode is most easily addressed. The grooves for the spring clips were found to be too narrow, preventing the clips from entering the grooves. Westinghouse has now cut the grooves wider so that the clip is completely relaxed when the clip is on the shaft properly, thereby requiring significantly higher forces to cause the clip to move out of the groove.

With the clip relaxed in the groove, the clips will deform and break if enough force is exerted on them to remove them. This amount of force does not occur due to any normal operation of the device.

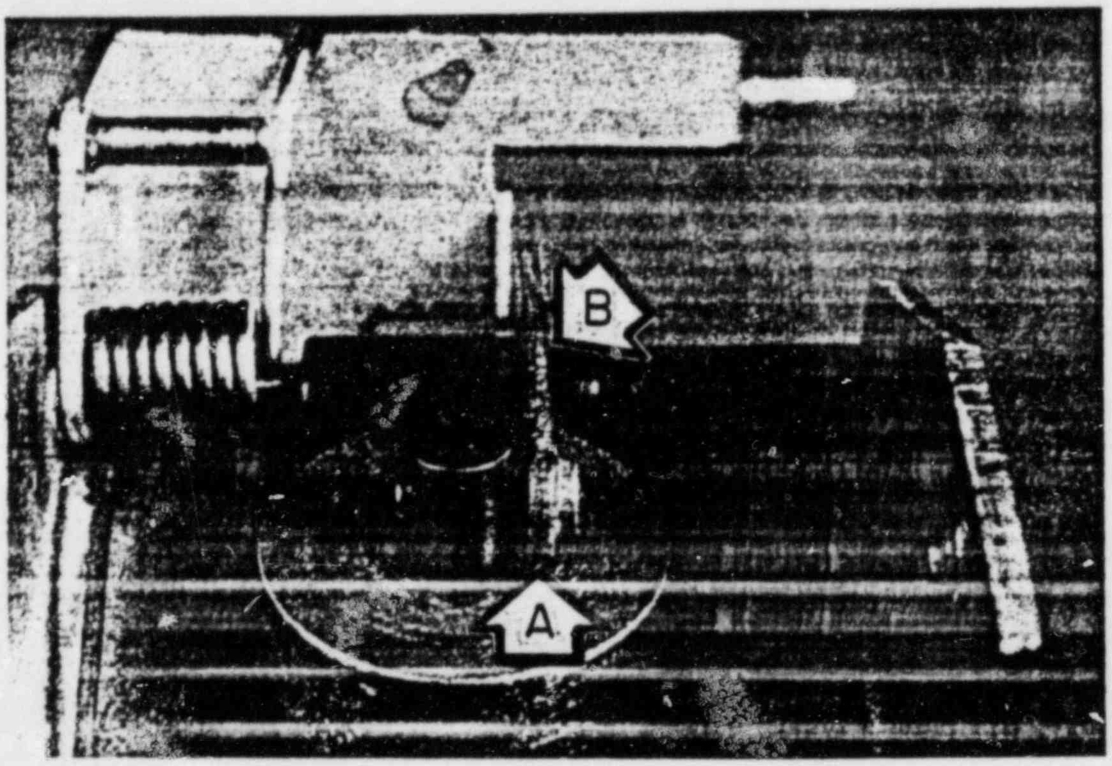

Figure 3. UVTA from Face with Reset Lever Bracket Removed

A. Moving Core to Roller Bracket Clearance

B. Spacer Bushing to Roller Bracket Clearance

The manufacturer's corrective action for the second failure mode was to reject devices with less than 0.018-in clearance between the moving core and the roller bracket arm and to establish a minimum clearance of 0.030 in between the roller bracket and the brass bushing. This clearance is required to prevent the bushing from causing a lateral force that pinches the bracket between the frame and the bushing. This pinching would act as a braking mechanism and prevent unlatching of the UVTA.

The second failure mode of improper positioning of the trip tab with respect to the trip bar rolled pin (trip pin) is critical in two directions, in that the UVTA trip tab must be neither too close nor too far from the pin. The manufacturer's recommended corrective action to prevent positioning problems is to measure the clearance between the trip bar pin of the circuit breaker and the trip tab of the UVTA with the circuit breaker closed and latched and the UVTA armed. Duke personnel found that small drill bits held by a needle-nosed pliers could be used to make this measurement. The drill bit that exactly fit between the pin and the trip tab was then measured and recorded. A minimum of 0.030 in is required. The manufacturer refers to this clearance as "pre-travel." To assure that the trip tab had adequate remaining travel (post-travel) to cause the circuit breaker latch to trip, the manufacturer required that a shim be placed between the reset arm bracket and the brass bushing on the roller bracket pivot pin. If the UVTA can successfully trip the circuit breaker with a 0.070-in-thick shim in place, the UVTA has adequate trip margin. (Note: Trip margin is the manufacturer's term. The shim is called a trip margin gage.) For this test, Duke personnel used drill bits to determine the trip margin.

3.2 OPERATION OF UVTAs ON CIRCUIT BREAKERS

Following the discussion of failures and corrective measures, FRC requested that Duke personnel place three UVTAs which were in FRC's possession on the test circuit breaker (a Catawba Station DS-416) for observation of operation and performance of the clearance and force tests that are now recommended by Westinghouse. The UVTAs were the McGuire 1A UVTA that had failed to trip during tests, a Catawba unmodified UVTA (as originally

received with the circuit breakers), and a "modified," newly manufactured UVTA. A fourth device, the McGuire 2B UVTA, was brought to the McGuire plant; however, it was in the disassembled state and could not be tested on a circuit breaker.

The first device to be tried on the circuit breaker was the McGuire 1A UVTA. The pretravel gap measurement was taken, and then the trip margin gap test was attempted. This required tripping the circuit breaker by deenergizing the UVTA coil. The 1A UVTA coil was deenergized; however, the UVTA did not unlatch and trip the circuit breaker. Attempts were made to determine the cause of binding. The moving core was noted to release and move slightly, indicating that the core had not jammed. The device remained latched for 10 minutes or more until it was jarred while attempting to find the cause of binding. The failure to unlatch at the McGuire plant could not be repeated. The testing of the 1A UVTA and the other two UVTAs was completed on the Catawba circuit breaker without further failures to unlatch.

NOTE: Subsequent to returning to Philadelphia, FRC determined that the source of binding of the 1A UVTA was inadequate clearance between the roller bracket and its brass spacer bushing, which caused a braking action that prevented unlatching. FRC succeeded in having the device remain latched while deenergized several times. The clearance between the bushing and the roller shaft was such that failure would occur occasionally rather than continuously.

3.3 MEASUREMENTS OF UVTA OUTPUT FORCE AND CIRCUIT BREAKER TRIP BAR INPUT FORCE

Duke personnel demonstrated the methodology for measuring the force required to unlatch the circuit breaker and the output force from the UVTA.

The force required to trip the latch of the circuit breaker is measured by pushing on the trip bar pin of the manual tripping mechanism at approximately the same point at which the UVTA would strike its trip bar pin. A horizontal spring scale is used. The measurements vary from reading to reading. Since the method is not highly precise, an average of multiple measurements is required.

The measurement of available output force that can be performed on the McGuire plant circuit breakers is a static pull of the reset lever from the

point just in front of the tab that is above the roller bearing when the device is latched (see Figure 4). Duke personnel perform this test with the UVTA unlatched, causing the trip spring to be in the most relaxed operating state. This reading is conservative with respect to a reading taken with the trip spring in the latched position and compensates for the pivot point frictions that would reduce initial output force slightly. A multiplier of 0.88 must be used to adjust these forces to account for lever arm differences.

Duke personnel also demonstrated the technique for determining UVTA output force on circuit breakers of slightly newer vintage than those of the McGuire plant. This technique was demonstrated on the Catawba Station DS-416 circuit breaker that was at the McGuire plant. For this test, the UVTA is reset and energized, and the circuit breaker contacts are restrained in the closed position. The circuit breaker trip mechanism is released, allowing the trip bar to rotate freely for a limited arc. The UVTA reset arm is also allowed to rest on the roller of the latch. The output force of the UVTA is measured by pulling on the backside of the manual-trip trip bar pin with the horizontal spring scale. This causes the UVTA trip bar pin to rotate against the UVTA's trip tab, causing the UVTA trip spring to wind tighter. The measurement is read when the reset lever begins to move. The output force measured by this method is less conservative than the force measured by the first method described, since the trip spring is measured at the highest operating force level (most tightly wound position). Also, the pivotal friction and the friction of the trip bar pin to UVTA trip tab interface would cause the measurements to be slightly higher than actually available.

Duke personnel provided the measured values for the McGuire Units 1 and 2 RTCBs. The force required to trip the circuit breaker latches ranges from a low of 0.25 lb to a high of 1.5 lb. The range of the UVTA outputs (after application of the 0.88 multiplier) was from 3.1 to 4.4 lb. The minimum ratio of the two forces was 2.6.

3.4 TRIP TIMING OF CIRCUIT BREAKER OPERATION BY UVTA

FRC requested that Duke personnel provide the timing of opening of the McGuire Units 1 and 2 RTCBs from time of deenergization of the UVTA coil until

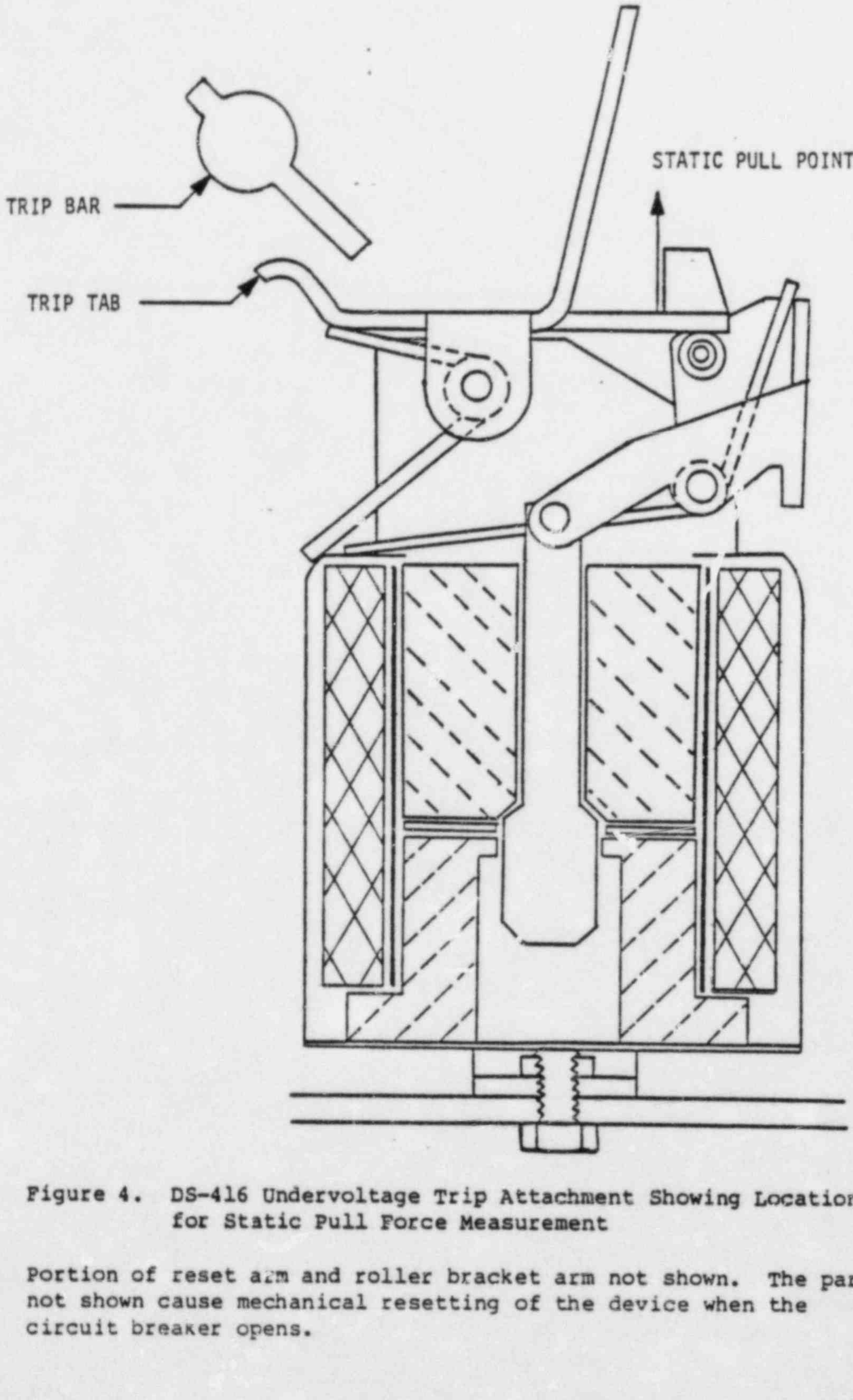

Figure 4. DS-416 Undervoltage Trip Attachment Showing Location for Static Pull Force Measurement

Note: Portion of reset arm and roller bracket arm not shown. The parts not shown cause mechanical resetting of the device when the circuit breaker opens.

contact opening. The timing charts provided by Duke personnel indicated a maximum allowable time of 0.150 sec. The actual recorded trip times ranged from 0.065 to 0.080 sec.

3.5 SUMMARY OF MANUFACTURER'S ACCEPTANCE CRITERIA FOR UVTAs

The following summarizes the acceptance criteria described above which preclude the failure modes recognized by the Licensee and Westinghouse.

1. Pivot shaft spring clips must be fully relaxed and seated in shaft grooves.

2. The clearance between the moving core and the roller bracket arm must be at least 0.018 in.

3. The clearance between the spacer bushing and the roller bracket must be at least 0.030 in.

4. A minimum gap of 0.030 in must exist between the trip tab of the UVTA and the trip pin of the circuit breaker with the circuit breaker closed and the UVTA energized.

5. Successful tripping of the circuit breaker must occur with the 0.070-in trip margin gage between the spacer bushing and the reset lever arm.

The acceptance criteria are expected to be applied to all DS-416 circuit breakers in service as reactor trip circuit breakers.

4. EVALUATION OF UVTAs AT FRC

Prior to and following the trip to the McGuire plant by FRC personnel, further evaluation of the four UVTAs in the possession of FRC was performed. The dropout voltage of the UVTAs was determined for each, tendencies to remain on latch after deenergization was investigated, dimensional checks were made, and the disassembled device (McGuire 2B) was reassembled and tested.

The force balance between the roller bracket spring and the solenoid were determined.

4.1 CHARACTERIZATION MEASUREMENTS

The McGuire 2B UVTA was carefully measured to determine whether interference between moving parts could inhibit the operation. Mechanical dimensions were measured, and the forces developed by the trip spring, roller bracket spring, and solenoid moving core were determined.

4.1.1 Mechanical Dimensions

The mechanical dimensions were obtained from the disassembled 2B UVTA. A surface plate was used as a reference plane. A dial indicator mounted on a vernier height gage, a vernier caliper, a 1-in micrometer, and a 1- to 2-in micrometer were used to make these measurements.

The measurements obtained for the critical areas are shown in Figure 5. The position shown is for the reset condition where the roller bracket is pressed down against the operating rod. With the rod firmly against the side of the hole in the moving core, the core would clear the sleeve by 0.0086 in. However, the diameter of the core does vary by 0.010 in, which would reduce the clearance to 0.0036 in.

As the roller bracket is rotated toward unlatching by the roller bracket spring, the operating rod is pulled toward the center line of the sleeving; at the extreme, the center line of the rod will be 0.005 in past the center line of the sleeving. This motion did not show any tendency to prevent the core

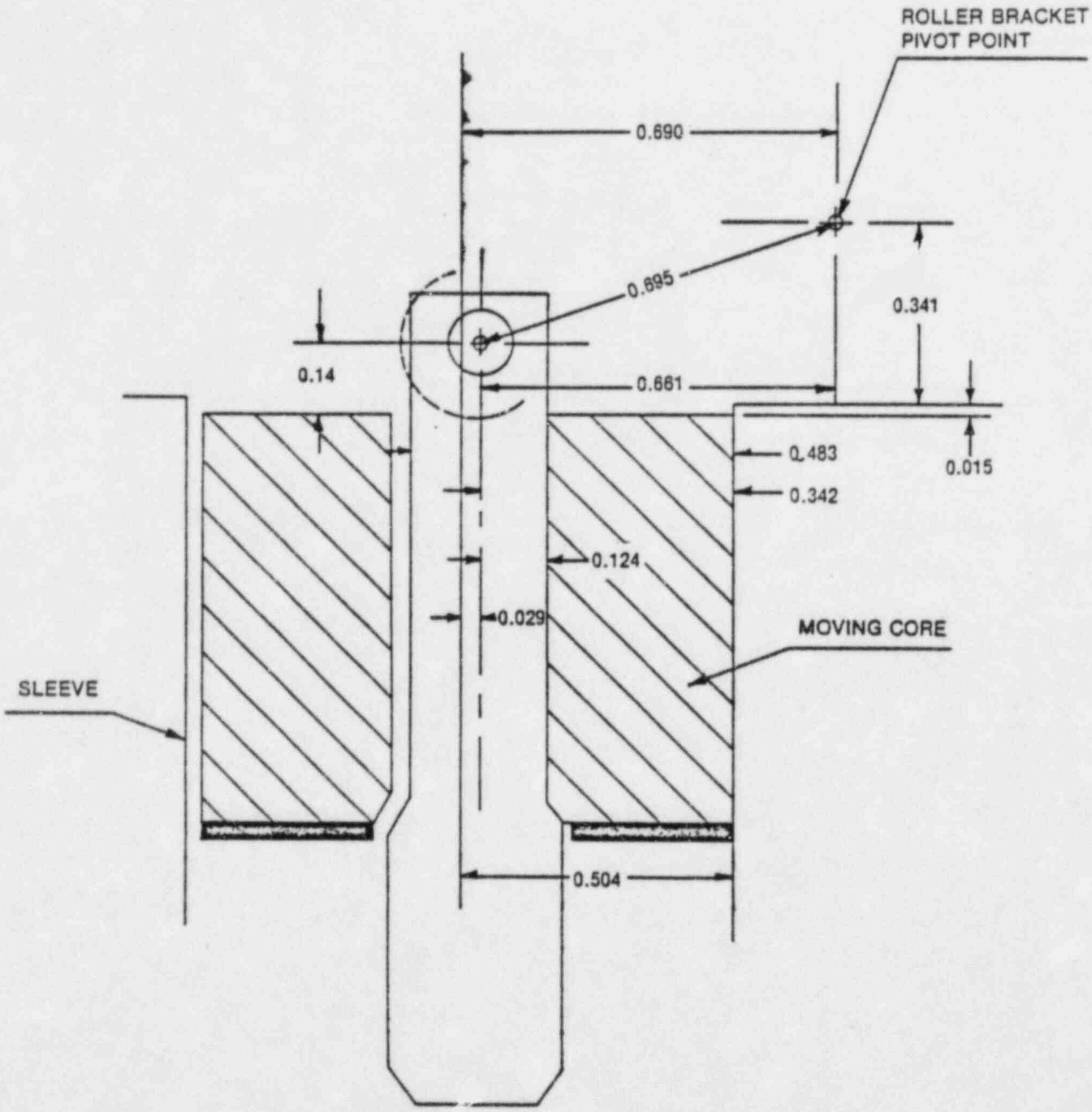

Figure 5. DS-416 UVTA in Reset Position
(Partial View Showing Critical Measurements)

from moving during the full range of core travel from reset position to the fully tripped position.

4.1.2 Forces Developed

The forces and/or torques were measured to determine the levels involved that cause the roller bracket to move out from under the reset lever. Once the roller bracket roller is clear of the reset lever, the trip tab of the UVTA rotates as driven by the trip spring, striking the pin that projects from the trip bar of the circuit breaker and resulting in the opening of the circuit breaker.

The first spring to be measured was the trip spring. In the position associated with the untripped condition, the force exerted against the roller was 3 lb (48 ounces). (Note: this measurement was made on the McGuire 2 UVTA; for other UVTAs, this force could range from 4 to 6 lbs). Since the force is nearly constant as the roller moves under the reset lever, the torque acting on the roller bracket can be evaluated as a function of bracket position. The equation for the torque is $T_{TS} = (48)(\sin \theta)(0.619)$ ounce-inches, where θ is the angle of the roller arm with zero reference found when the roller is directly under the reset lever, thus producing no rotating torque on the roller bracket. The 0.619 in is the radius arm of the roller from support bearing. In the latched position the angle is approximately 6 degrees, thus producing a torque of 3.1 ounce-inches that add the torque resulting from the force produced by the coil.

The force developed by the coil was measured by pulling directly upward on the operating rod with a spring scale. No other linkages were involved in this measurement. The data obtained at various excitation voltages are plotted in Figure 6. As noted on the data plot, the force does drop to a reduced level once the core has moved away from the washer separating it from the stationary core. The torque developed by the moving core is expressed as $T_{MC} = \cos(\theta-13)(F_{MC})(0.695)$. This shows that as the moving core leaves the untripped position, the torque tends to increase until θ reaches a level of 13 degrees, where the torque would be approximately 6% higher. However, as

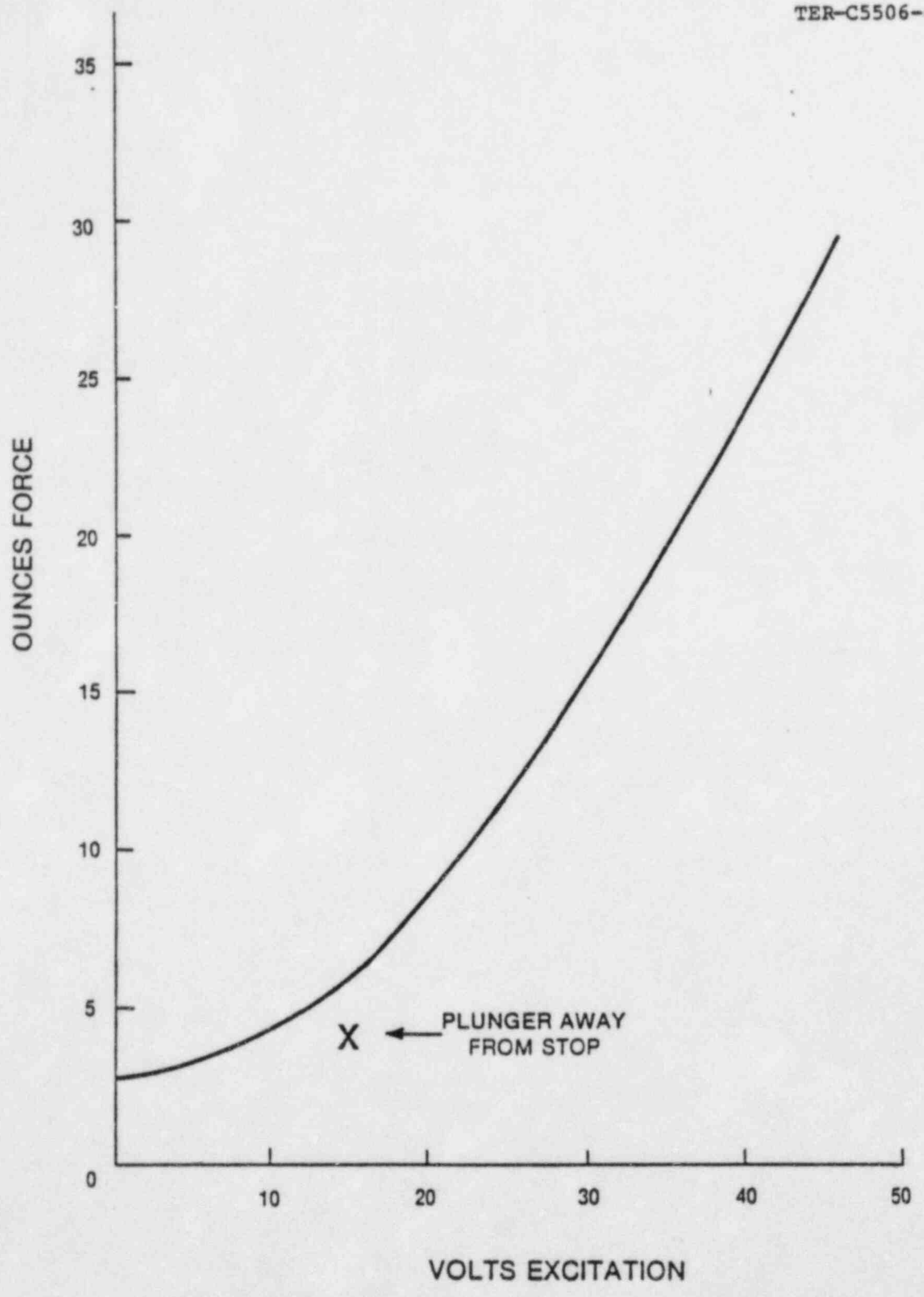

Figure 6. Force Developed by Moving Core versus Coil Excitation Voltage

soon as the core moves, the force of the moving core is reduced approximately 30% due to the increased air gap.

Another observation related to the forces developed by the moving core is that as the core moves down with excitation voltage applied, it will pull down first on the side closest to the roller bracket support shaft. This cocks the moving core, but when in the final position, the core is straight; in many attempts, the core could not be forced to assume a position that would prevent normal trip operation.

The torque developed by the roller bracket spring (T_{RBS}) was determined by use of a spring scale with all other linkages disconnected. The data obtained from these measurements are plotted in Figure 7. As the roller bracket rotates bringing the moving core up from the stop, the torque is constantly decreasing.

The combined result of these systems is plotted in Figure 8. The roller torque is not shown.

4.1.3 Discussion of Roller Bearing

The roller element bearing is not symmetrical because the rollers extend to one end of the bearing housing, but only come to about 75% of the distance from the other end. With the rollers directly under the reset lever, the system will trip consistently. When the bearing is reversed on the mounting shaft, the reset lever now applies force at one end of the rollers. In this configuration, the assembly can be made to fail.

Further confirmation of the effect of increased friction was studied by taking a brass brushing with the same dimensions as the roller bearing and placing it on the bearing shaft. The assembly could readily be made to fail. The maximum torque level for the rolling friction can then be determined from Figure 7. Since the slope of T_{RBS} is less than that for the T_{TS}, the rolling friction would have to be less than 10.6 ounce-in at an angle of -6 degrees.

During the investigation, an attempt to stop operation of the UVTA was made by placing debris on the roller. Debris on the order of 0.0025-in thick

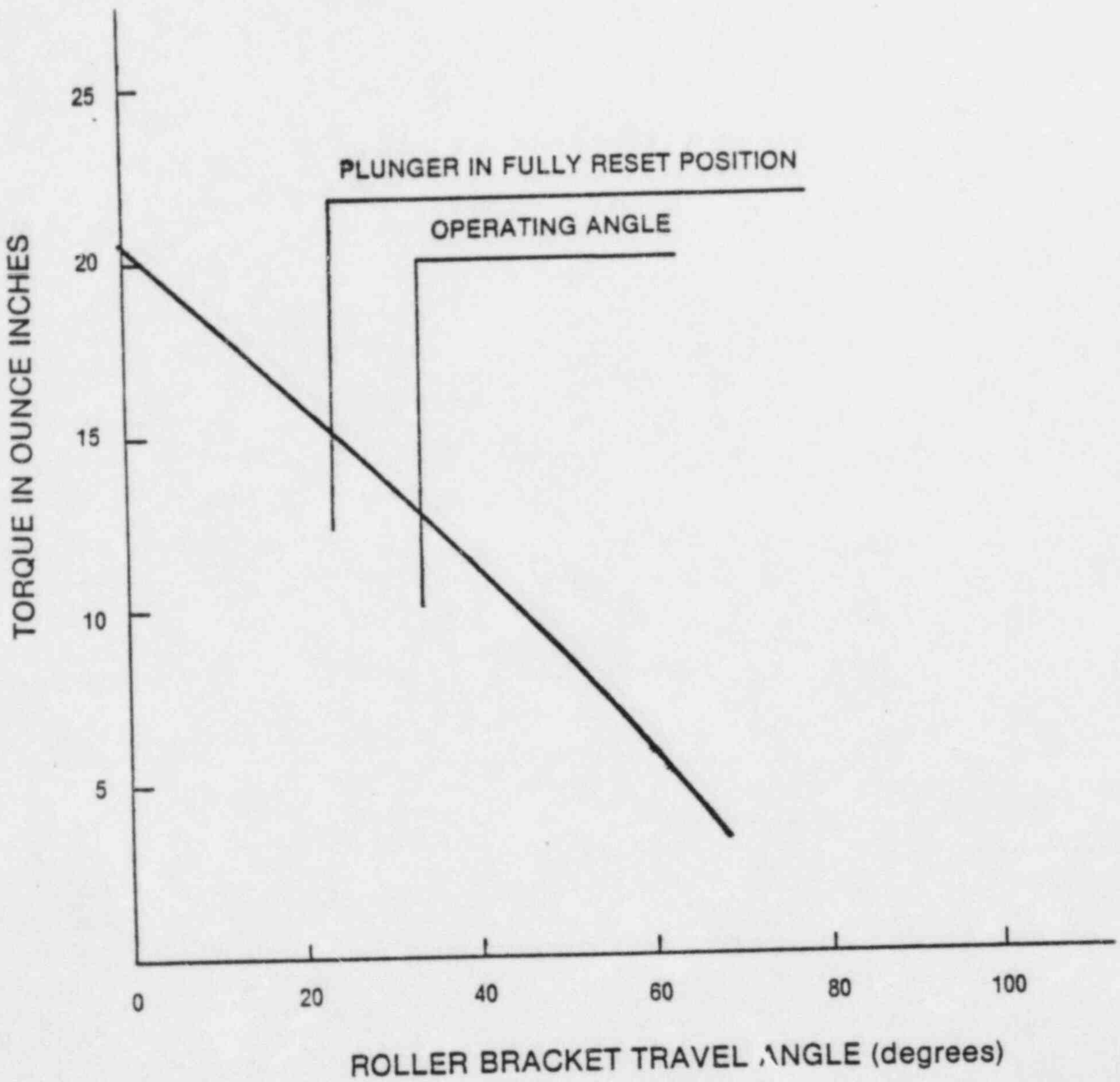

Figure 7. Torque Developed by Roller Bracket Spring versus Angle of Travel of Roller Bracket

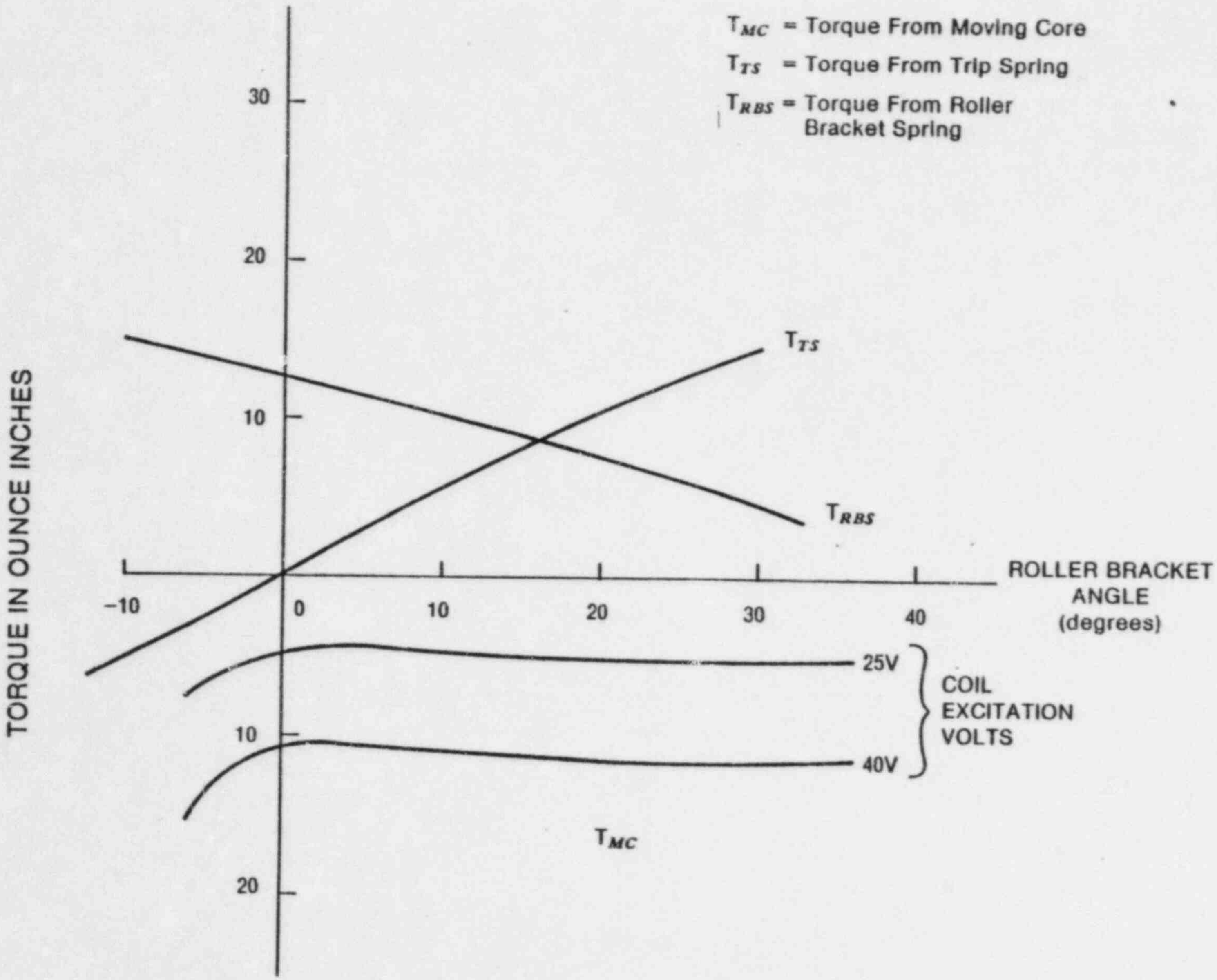

Figure 8. Roller Bracket Torque versus Angle of Roller Bracket

did prevent operation when placed in a manner so that it acted as a chock preventing the roller bearing from rolling on the undersurface of the reset lever bracket.

Since increased friction in the operation of the roller bearing or debris on the roller bearing surface would tend to reduce probability of operation, further evaluation of the roller bearing is appropriate. During operation, the circuit breaker cabinet prevents extraneous material from being deposited upon the bearing. The only significant possibility for debris to be deposited in the roller area would be during inspection or maintenance periods. Reasonable care and cleanliness at times of inspection and maintenance would preclude debris from being a problem. Friction in the roller bearing could increase with age if the bearing grease accumulated dirt or dried out. To date, this does not appear to be a significant problem. The bearings in use at McGuire were on the order of ten years old and the grease did not show signs of significant degradation.

5. CONCLUSIONS

The FRC evaluation indicates that the failure modes recognized by Duke and Westinghouse personnel (i.e., clearance problems within the UVTA, clearance problems between the trip bar pin and the UVTA, and pivot shaft spring clip failure) have been corrected. However, evaluation of the overall operation of the UVTA causes FRC to be concerned about the roller bearing on the roller bracket.

The roller bearing is critical to the operation of the device and slight changes in rolling friction rapidly reduce the margin for correct unlatching of the UVTA. While failure to unlatch caused by roller bearing friction has not occurred to date, closer evaluation of the potential of such failures is prudent.

Debris on the roller bearings could prevent unlatching of the UVTA. However, when the circuit breaker is in its compartment, the UVTA is well protected from contamination. If the bearing is kept clean during maintenance and inspection, the concern for debris-related failures is eliminated.

Acceptance criteria have been set for critical measurements for the UVTA by the manufacturer. UVTA output force, circuit breaker trip force, bushing clearances, and clearances of UVTA with respect to the circuit breaker trip bar pin all have criterion set. Testing methodology has been developed for each of these criterion. Baseline tests for determining whether the McGuire reactor trip circuit breakers meet the criteria have been performed.

6. RECOMMENDATIONS

1. Following maintenance, the outer surface of the roller bearing and the mating surface of the reset lever should be inspected for cleanliness. No debris of any kind should be on these surfaces. The roller bearing should be checked for free rotation.

2. The baseline tests on the UVTAs and circuit breakers should be repeated periodically and the data compared to baseline data and trended in order to determine degradation.

3. Life testing of the UVTA should be performed to show that the device can successfully operate for the intended lifetime.

4. Criteria for a replacement interval should be developed for the UVTA so that replacement occurs significantly before the expected end of life. These criteria should be based on the life testing of Recommendation 3.

5. The roller bracket to roller bearing frictional forces should be reviewed and evaluated. Potential for failure to operate should be determined, and any significant potential for failure should be eliminated. Data available at the time of writing of this report indicated that there is no immediate short-term concern for roller bearing failures and that this evaluation could be performed in conjunction with the life testing program.