



AEROSPACE RECOMMENDED PRACTICE

ARP6157™**REV. A**Issued 2017-05
Revised 2020-06

Superseding ARP6157

(R) Pressure-Viscosity Coefficient Measurement

RATIONALE

The pressure-viscosity coefficient of lubricating oils is an inherent property for generating EHD films. It is used in rolling element bearing and gear design calculations for predicting EHD film thickness and for estimating wear life, scuffing resistance, and contact fatigue life. Pressure-viscosity is a report item in AS5780 and the measurement method is currently described in an appendix of AS5780. Improvements in the measurement technique and the identification of the operating speeds to avoid thermal effects have provided recommended test conditions for measurement.

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1. SCOPE

The lubricant performance capability for aero propulsion drive systems is derived from the physical properties of the oil and performance attributes associated with the chemical properties of the oil. Physical properties, such as viscosity, pressure-viscosity coefficient and full-film traction coefficient are inherent properties of the lubricating fluid. Chemical attributes are critical for the formation of protective boundary lubricating films on the surfaces to prevent wear and scuffing. These attributes are also associated with surface initiated fatigue (micropitting). To assure performance and to provide required information for engineering design, methodology for at least five oil properties are being studied: (1) pressure-viscosity coefficient, (2) full-film traction coefficient, (3) scuffing resistance, (4) wear resistance, and (5) micropitting propensity. The pressure-viscosity coefficient can be measured either directly by assessing viscosity as a function of pressure using high-pressure apparatus, or indirectly by measuring film thickness in an optical interferometer. This document (ARP6157) describes the following two alternative test instruments for calculating the pressure viscosity coefficient by measuring the fluid film thickness:

i. PCS EHD2 test instrument

ii. WAM test machine

Both methods have been shown to give similar results, therefore either method can be used to calculate the pressure viscosity coefficient of a sample lubricant. For details of how to set up and run either method, see Section 7 (PCS-EHD) or Section 8 (WAM).

1.1 Purpose

The purpose of this test method is to measure the elastohydrodynamic (EHD) film thickness of a test oil over a specific range of entraining velocities, five temperatures and one Hertzian contact stress. The test conditions presented here are suitable for a range of oil viscosities, including commonly used aviation oils with viscosities between 3 cSt and 10 cSt. The measured EHD film thickness is used to calculate the pressure-viscosity coefficient at each test temperature from a commonly used Hamrock and Dowson film thickness equation [1, 2] shown in Figure 1. The pressure-viscosity coefficient is used in design, along with other physical properties of the oil, such as viscosity and traction coefficient. The five selected temperatures for measurement are common to other properties, as reported in AIR5433B [3].

2. REFERENCES

2.1 Applicable Documents

The following publications form a part of this document to the extent specified herein. The latest issue of SAE publications shall apply. The applicable issue of other publications shall be the issue in effect on the date of the purchase order. In the event of conflict between the text of this document and references cited herein, the text of this document takes precedence. Nothing in this document, however, supersedes applicable laws and regulations unless a specific exemption has been obtained.

2.1.1 SAE Publications

Available from SAE International, 400 Commonwealth Drive, Warrendale, PA 15096-0001, Tel: 877-606-7323 (inside USA and Canada) or +1 724-776-4970 (outside USA), www.sae.org.

AIR5433 Lubricating Characteristics and Typical Properties of Lubricants Used in Aviation Propulsion and Drive Systems

AS5780 Specification for Aero and Aero-Derived Gas Turbine Engine Lubricants

2.1.2 ASTM Publications

Available from ASTM International, 100 Barr Harbor Drive, P.O. Box C700, West Conshohocken, PA 19428-2959, Tel: 610-832-9585, www.astm.org.

ASTM D341 Standard Practice for Viscosity-Temperature Charts for Liquid Petroleum Products



Documents

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2.2 Related Publications

The following publications are provided for information purposes only and are not a required part of this SAE Technical Report.

Hamrock, B.J. and Dowson, D. "Isothermal Elastohydrodynamic Lubrication of Point Contacts, Part III – Fully Flooded Results", J. Lubr. Technology, Vol. 99, No. 2, Feb 1977, pp. 264-276.

Hamrock, B.J., and Dowson, B. "Ball Bearing Lubrication – The Elastohydrodynamic of Elliptical Contacts", Willey, 1981.

3. APPROACH

1. Using either method described in Sections 7 or 8, the process is the same for any sample lubricant:
2. Run a known reference fluid at set, controlled temperatures and measure the film thickness
3. Using the reference oil viscosity, confirm that the pressure viscosity is in line with expected values - confirms instrument is correctly set up and calibrated
4. Measure the viscosity of the sample fluid
5. Run the sample and measure the film thickness at set temperatures and speeds
6. Using the Hamrock and Dowson equation (shown in Figure 1), calculate the pressure viscosity value
7. Report the calculated α_{sample}

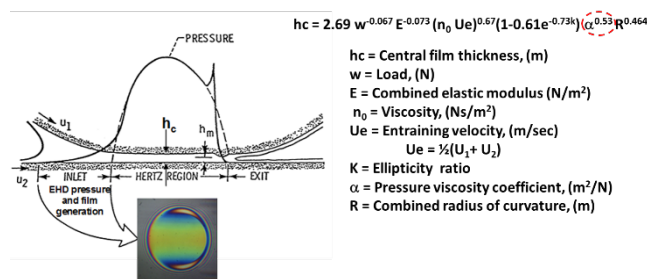


Figure 1 - Inlet zone pressure generation and EHD parameters for oil film thickness

4. REFERENCE FLUID

It is recommended that the user runs a reference fluid prior to running the proposed test oil sample to help confirm that the test instrument is within calibration limits. One reference fluid that has been found to be satisfactory for the pressure viscosity coefficient calculation is 2-ethylhexyl-sebacate (DEHS) - a pure chemical that has been characterized in different labs using different techniques (both EHL and high-pressure viscometer). The Hamrock and Dowson predicted film thickness results and PCS Instruments EHD test results using the DEHS reference fluid is shown in Figure 2 – showing good correlation between the two different sets of values for a range of temperatures.

5. PRECISION STATEMENT

The accuracy and resolution of the calculated pressure-viscosity is largely a function of the accuracy of the film thickness measurement and the accuracy of the input for the test oil viscosity. The film thickness accuracy is ± 5 nm and the temperature accuracy is ± 2 °C. The corresponding effect on the accuracy of the calculated pressure-viscosity coefficient (using either type of instrument described in Sections 7 and 8) is $\pm 0.15 \times 10^{-8} \text{ Pa}^{-1}$

6. REPORTING THE RESULT

If a reference fluid has been used, then after confirming that the reference fluid is within the correct range and the test fluid has been run, then the resulting pressure viscosity coefficient value (α -value) of the test fluid at each temperature run is reported along with the instrument used to run the test.

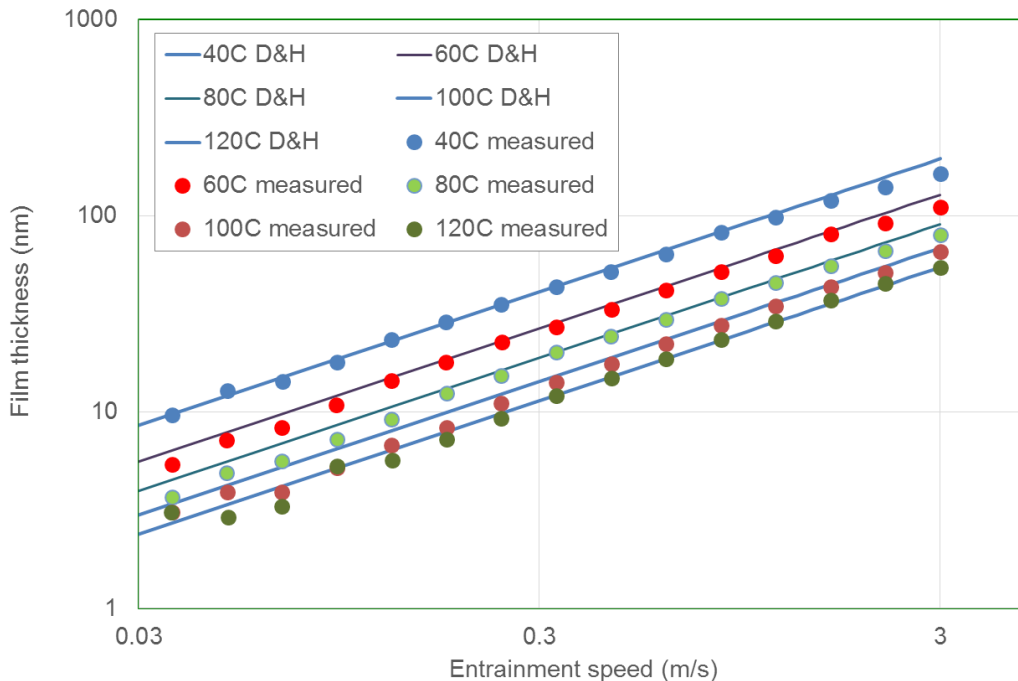


Figure 2 - Film thickness results from DEHS reference fluid Hamrock and Dowson predicted vs. PCS EHD test results at 5 separate temperatures

7. PCS EHD METHOD

The following method uses the PCS Instruments EHD2 test instrument (Figures 3 and 4). The test approach requires an accurate measurement of EHD film thickness under controlled surface motion, contact stress and thermal environment. The controlling parameters for EHD film thickness (h_c) have been illustrated in Figure 1 for a point contact configuration.

The PCS EHD test machine configured for optical interferometry is shown in Figure 4. The test configuration consists of a transparent optical disc which is loaded and rotated against a smooth steel ball. The contact is lubricated with the test fluid and operated in pure rolling motion. Partially reflecting optical coatings on the disc allow light interference fringes to form between the ball and disc surfaces. The coatings typically include a thin “spacer layer” of SiO_2 which has a refractive index similar to typical oils. A spacer layer of known thickness avoids zero-order fringes where the separation thickness is too small to get sufficient interference of light.

Further details on setting up the equipment to run a film thickness experiment can be found in the EHD standard manual supplied with the instrument.

7.1 PCS Alpha Value Test Procedure

Using the reference fluid described in Section 5, set up the instrument as described in the EHD user manual to run a standard film thickness test.

When selecting the profile, select the ‘ARP6157’ profile, and select an appropriate test data filename – see Figure 5.

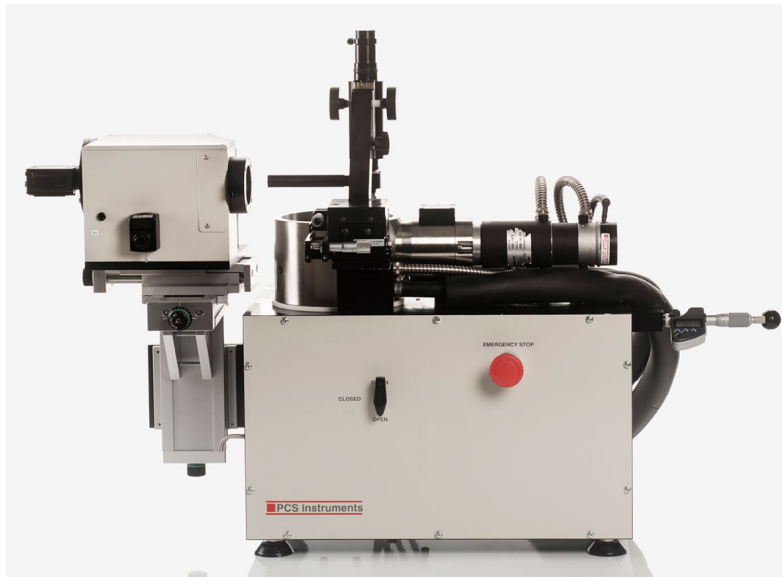


Figure 3 - PCS instruments EHD test instrument



Figure 4 - PCS Instruments EHD Test Instrument - close up of test chamber for film thickness test

A screenshot of the 'New Test' dialog box in the EHD software. The dialog box has a title bar 'New Test' and a close button. It contains several fields and buttons: 'Profile File' (C:\Users\Administrator\Documents\profiles\test profile.ehdp), 'Profile Description' (high speed range in 80 degree C cc), 'Output File' (C:\Users\Administrator\Documents\tests\test 1.ehdd), 'Track radius (mm)' (38.998), 'Lubricant Name' (test lubricant), 'Lubricant Property File' (C:\Users\Administrator\Documents\1_4.lpf), 'Properties Description' (empty), and 'Comments' (test 1). There are 'Browse...' buttons next to the file fields. At the bottom, there are 'Start Test' and 'Cancel' buttons.

Figure 5 - Choose the profile ARP6157 and test output filename in the EHD software

Run the test as described in the manual. Once the test is completed, open up the ARP6157 Application and select the test data file you have just run (Figure 6).

Enter the viscosity for the sample and the App will automatically output the pressure viscosity values with respect to temperatures that you have run using the Hamrock and Dowson equation (Figure 1).

Report this value for your desired temperature.

Figure 6 - Pressure viscosity app for the PCS EHD2 instrument

8. WAM METHOD

The WAM test machine configured for optical interferometry is shown in Figure 7. The test configuration consists of a transparent optical disc which is loaded and rotated against a smooth steel ball. The contact is lubricated with the test fluid and operated in pure rolling motion. Partially reflecting optical coatings on the disc allow light interference fringes to form between the ball and disc surfaces. The coatings typically include a thin “spacer layer” of SiO₂ which has a refractive index similar to typical oils. A spacer layer of known thickness avoids zero-order fringes where the separation thickness is too small to get sufficient interference of light.

The colored interference fringes are monitored with a microscope and camera. The color of the interference fringes changes when the separation (oil film thickness, h_c) of the ball and disc changes. The optical system captures the interference images and test conditions. Images are processed with the AChILES software from which the central film thickness is derived. Once the film thickness is obtained, the AChILES software calculates a P-V coefficient according to the Hamrock and Dowson equation [1, 2] for isothermal central film thickness. The calibration of the optical system and method for measurement of EHD film thickness, followed by the calculation of P-V coefficient are described in the sections below.

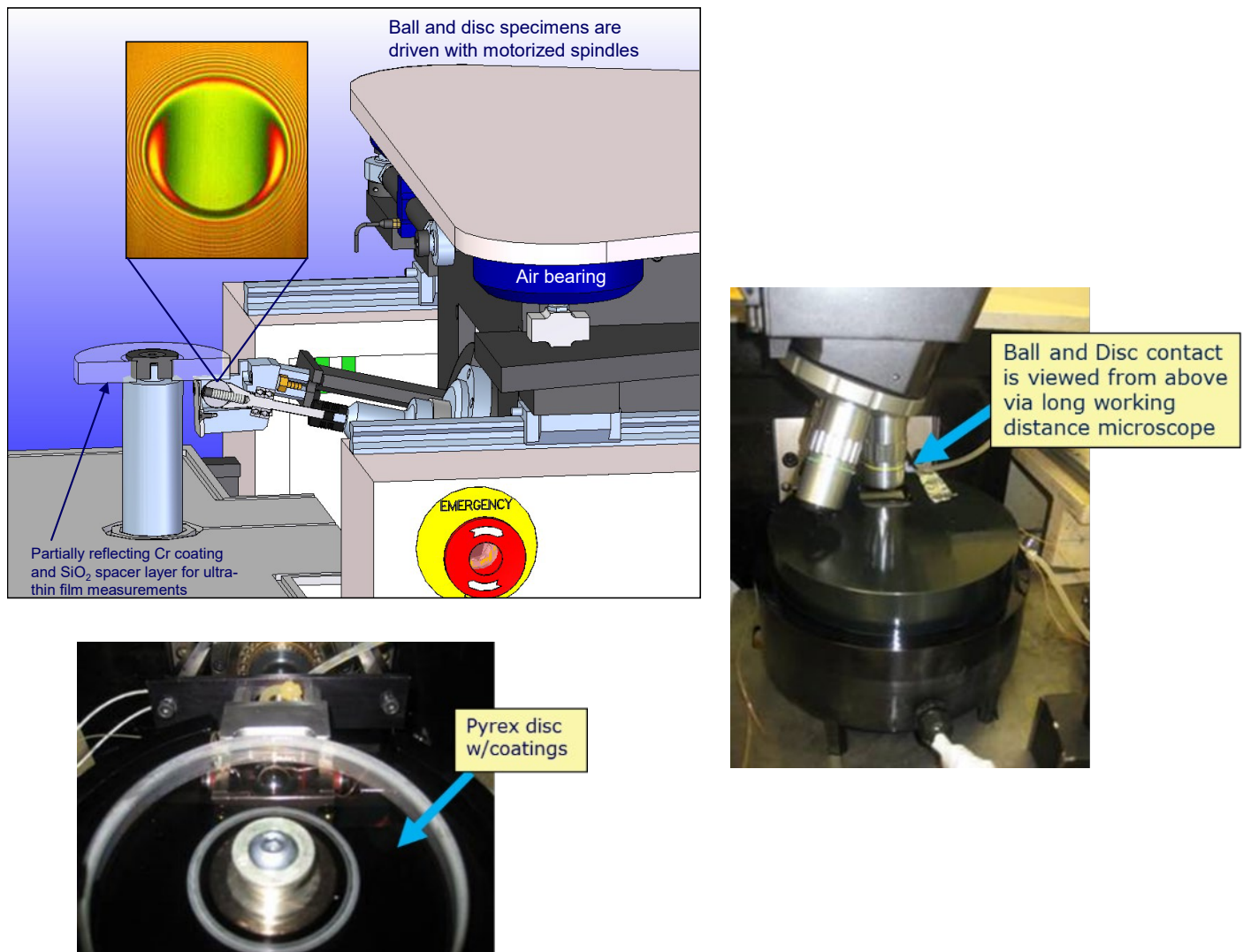


Figure 7 - WAM set up for EHD film thickness measurement

9. REQUIRED HARDWARE

9.1 WAM machine with driven ball optics capability.

9.1.1 114.3 mm (4.5 inch) diameter, 1.588 mm (0.625 inch) thick, Tempered Pyrex 7740 disc with optical coatings on Side A and Side B, see Figure 8.

9.1.2 Side A: Anti-reflective MgF_2 coating.

9.1.3 Side B: Partially reflective Cr, followed by 200 nm thick SiO_2 layer, 5 mm wide radial strip with Cr only.

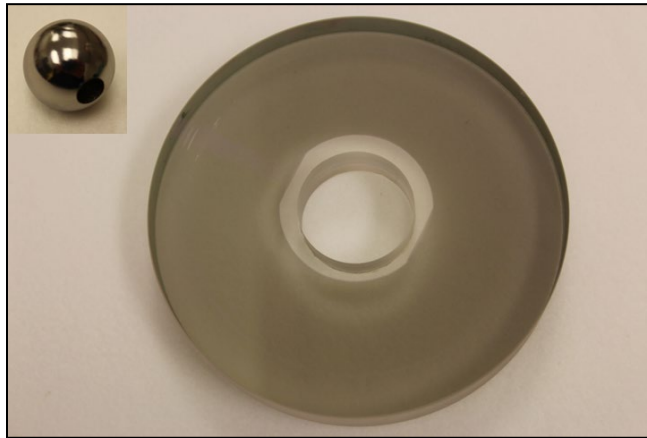


Figure 8 - Space layer optical disc and grade 10 M50 ball

9.2 20.64 mm (13/16 inch) diameter Grade 10 or better M50 ball with 6.48 mm (0.255 inch) through-hole, see Figure 8.

9.3 Optical disc clamp washer (to secure disc), see Figure 9.

9.4 3/8 inch-24X3/4 Flat head bolt (to secure disc), see Figure 9.

9.5 Modified precision shoulder bolt (to secure ball), see Figure 9.

9.6 Fiber optic cable bushing (for microscope), see Figure 9.

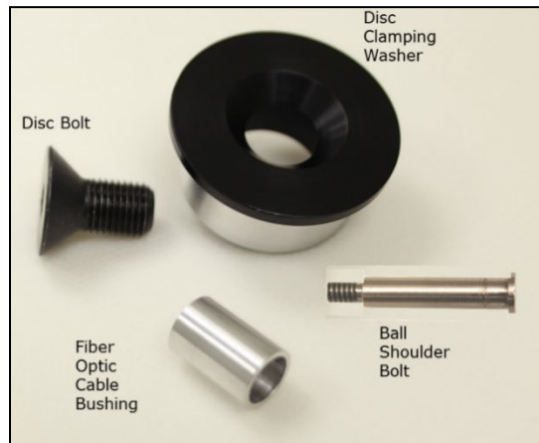


Figure 9 - Disc bolt, washer, ball bolt, and fiber optic cable bushing

9.7 Driven ball optics disc sump assembly, see Figure 10. WAM10 sump shown, others are similar.

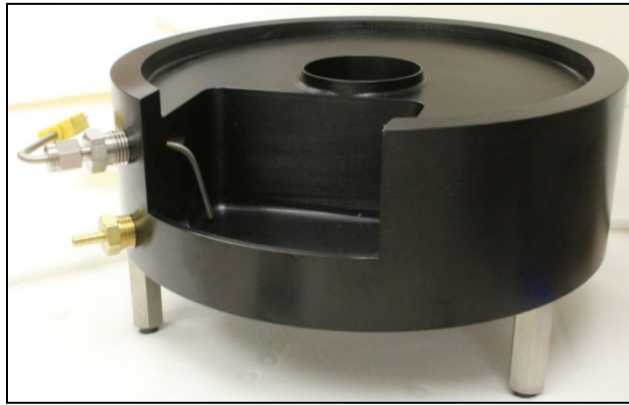


Figure 10 - Disc sump assembly

9.8 Driven ball optics nosepiece adaptor, see Figure 11. WAM10 adaptor shown, others are similar.



Figure 11 - Driven ball optics nosepiece adaptor

9.9 Driven ball optics assembly, see Figure 12. WAM9 assembly shown, others are similar.

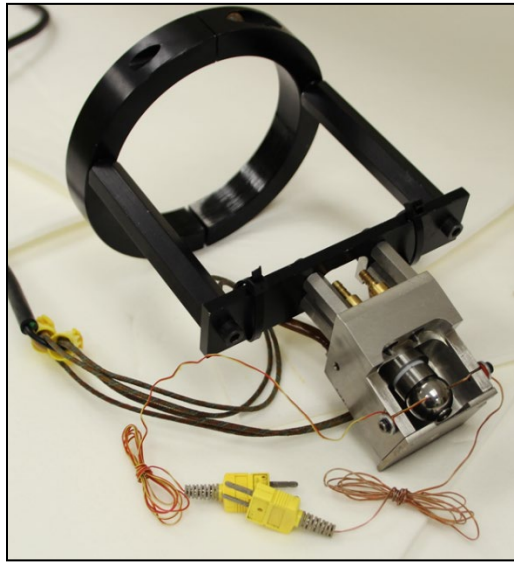


Figure 12 - Driven ball optics assembly

9.10 2.38 mm (3/32 inch) ID 5.56 mm (7/32 inch) OD translucent high temperature silicone rubber tubing and inline PVDF (2) micron filter, 135 °C (275 °F) capability, 6.35 mm (1/4 inch) tube fitting, see Figure 13.



Figure 13 - Silicone tubing and inline oil filter

9.11 Mituyo Microscope with 5X and 10X objectives, see Figure 14. Microscope shown, others similar.



Figure 14 - Microscope with 5X and 10X objectives

9.12 Microscope adaptor plate for attaching microscope to XY slide, see Figure 15. WAM9 plate shown, others similar.

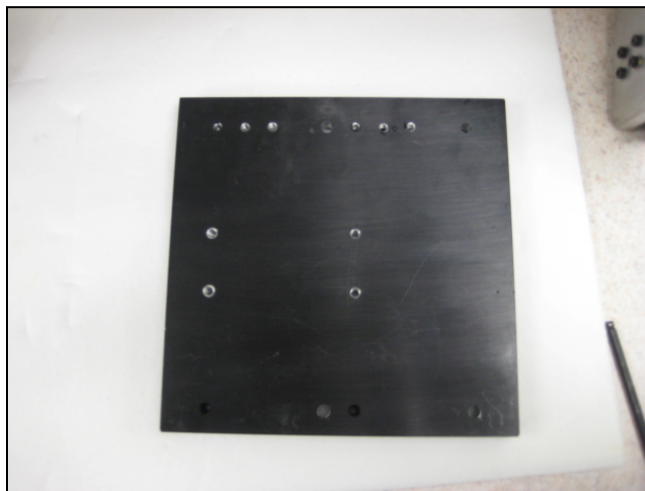


Figure 15 - Adaptor plate