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THERMAL CONTACT CONDUCTANCE - A COMPARISON OF METHODS

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14. Abstract/Notes

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THERMAL CONTACT CONDUCTANCE - A COMPARISON OF METHODS

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ABSTRACT

For the first Brazilian satellite thermal contact resistance calculation, it was necessary to determine, among several physical and mathematical models, the most suitable for the space conditions. First, three methods were selected and compared with literature experimental data, with the objective of stablishing the most appropriated one. It was concluded that the model developed by Mikic and Rohsenow [10] was the most indicated because it considers the heat flux macro and microconstriction influences.

1. INTRODUCTION

1.1. Thermal Contact Resistance Conception

The surfaces obtained in actual machining process present deformities, so that when put in physical contact, they touch each other in a restricted number of points. The surface roughness determines the true contact points and the waviness their geometrical distribution (see Figure 1); then a heat flux passing through this interface is first conducted to the contact point concentration zones and afterwards through these points. Due to this flux constriction, a temperature difference at the contact interface can be observed.

The thermal resistance conception is obtained from the analogy with the electric circuit Ohm's law. The heat transfer rate is analogous to a electrical flux and the temperature difference to electrical potential, so that:

$$\text{thermal resistance (R)} = \frac{\text{thermal potential difference } (\Delta T)}{\text{heat flux } (Q/A)}$$

The inverse of the thermal contact resistance is known as thermal contact conductance (h).

1.2. Objective of Work

The objective of this work is to compare the previously developed methods and to establish the mathematical model more suitable to use in the first Brazilian satellite.

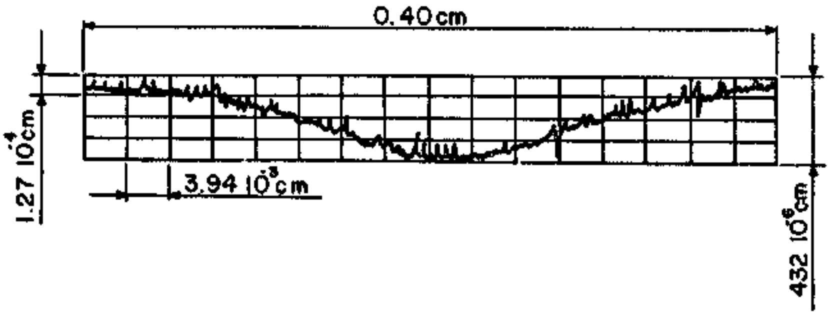

FIGURE 1. Typical surface linear profile showing waviness and roughness.

2. THERMAL CONTACT RESISTANCE WORKS

Too many parameters affect the thermal contact resistance, so it is very difficult to obtain a theoretical method that predicts, with precision, the thermal contact resistance for an arbitrary kind of surface contacts; it explains the fact that so many thermal contact resistance works have been done around the world. Only the most important parameters are listed here:

(1) contact points number;

(2) contact points shape;

(3) contact points size;

(4) contact points physical arrangement;

(5) surface roughness;

(6) surface waviness;

(7) contact pressure;

(8) interstitial fluid thermal conductivity;

(9) material hardness;

(10) elasticity modulus;

(11) mean interface temperature;

(12) mean interstitial fluid pressure;

(13) interfilling junction material;

(14) directional effect;

(15) coupling history with respect to the number of compressions and decompressions;

(16) surface oxide films,

2.1. Chronological Evolution

During nineteen hundred forties, when the necessity of the study of the heat transfer through a contact interface emerged, the first efforts in thermal contact resistance were developed. As this phenomenon was not known until that time, it was first investigated experimentally. The first experimental works had as objective the investigation of specific contacts concerning the projects in which the authors were involved, It happened with Brunot and Buckland [1], and Barzelay et al. [2], [3]. They developed extensive works in experimental measurement of contacts found in aeronautical projects. With these results, some researchers tried to stablish mathematical models to estimate the thermal contact resistance. Fried and Costello [4] were among the first to study the thermal contact resistance problems for space applications, They made the hypothesis that the heat was transferred through basic mechanicms, considered as parallel resistances: conduction through physical contact points, conduction through intersticial fluids, and radiation. This model did not consider the flux lines deformation.

Fenech and Rohsenow [5] created the first important model to simulate this mechanism; they considered that all the contact points were uniformly spread in surface contact, round, of uniform size, and cylindricals. Then, studying just one contact point was enough to evaluate the interface thermal contact resistance, Figure 2 shows the physical model that they adopted; D is the diameter of the unit cell, a_m and δ are the surface roughness mean radius and heigth, respectivelly.

Clausing [6], [7], [8] observed that, until then, the developed models presumed that the contact points were uniformly distributed in the coupling interface. This kind of distribution if found in interfaces between flat roughness surfaces, which are very difficult to obtain in the fabrication processes. The actual machined surfaces present waviness and roughness so that, when coupled, there are contact points concentration zones. Then the heat flux, to pass through the contact, suffers two kinds of constrictions: a microcontriction, expected in Fenech and Rohsenow model, and a macroconstriction. Clausing considered that the surface thermal contact resistance is formed by three resistances in series: the macroconstriction resistance, the microconstriction resistance, and surface oxide film resistance. In macrocontact area, this author conceived the surface waviness as spherical calottes (see Figure 3) and used the Hertz's theory [9] to calculate the contact area between pressured spherical surfaces, considering elastic deformation. He also assumed that the microcontacts are uniformly spread along the contact areas, and utilized the Hoess theory [6], [7], [8] to determine the microconstriction resitance. The oxide film resistance was not considered, because the tested surfaces were clean .i.e., without this film,

Mikic and Rohsenow [10] developed a mathematical model for a physical model similar to the Clausing's one. They concluded that the macro and microconstrictions were similar physical phenomena that could be described by the same mathematical formulation, using typical dimensions for each case. The macrocontact area was calculated using the Hertz's theory. These scientists verified that due to the roughness this area is a little greater than the estimated one and developed an equation to determine the area calculation more precisely. This theory can be used to calculate the thermal contact resistance together with its physical surface characteristics.

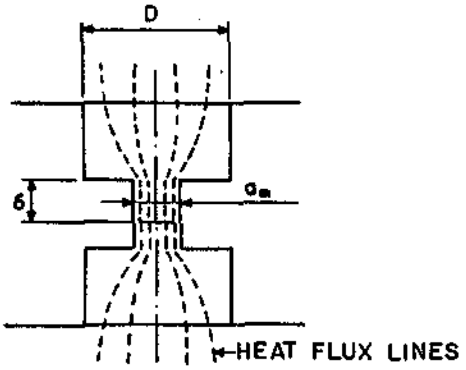

FIGURE 2. Fenech and Rosehnow's physical model.

Yovanovich and Rohsenow [11], using the Mikic and Rohsenow's equations, studied the contact points size variation along the interfaces and the contact points distribution monuniformity, for flat and rough surfaces. They analized the surface deformation and verified that there are regions with plastic deformation and others where the deformation is elastic.

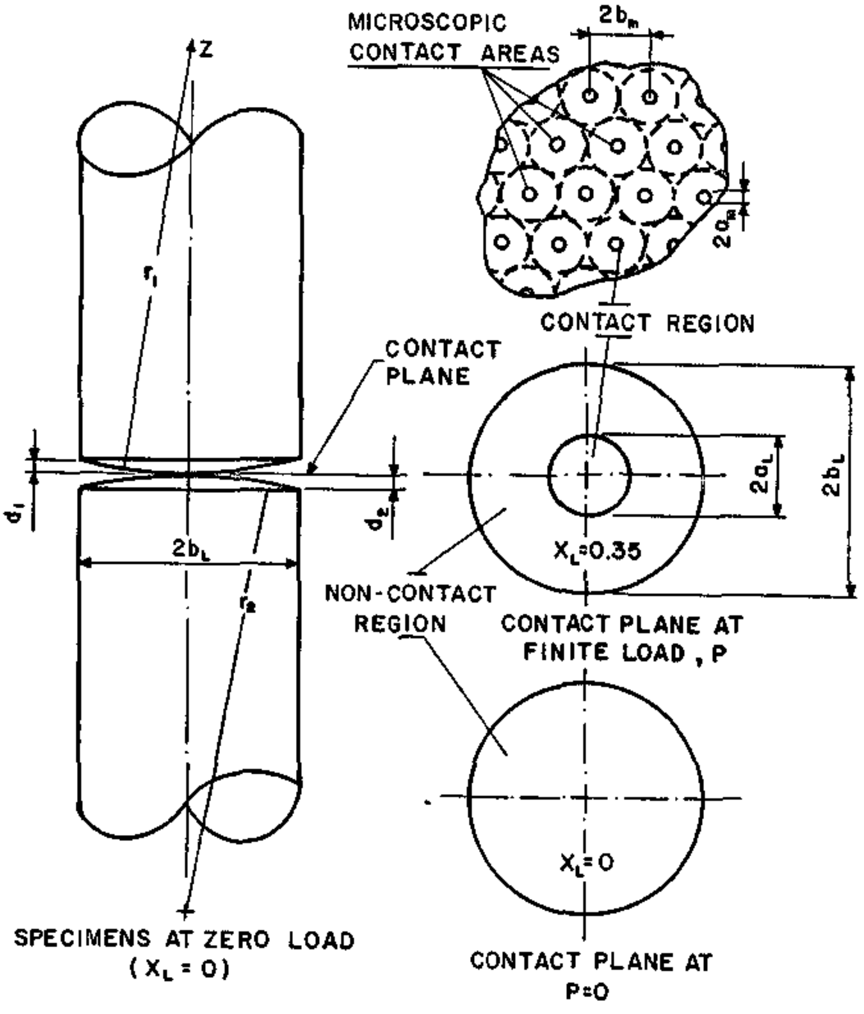

FIGURE 3. Macro and microcontacts.
Source: Clausing [8] pp:3.

At that time, some scientists observing that the surface parameters like asperity height and microscopic areas have a Gaussian distribution for most of the surfaces, began to use the statistic theory to get the necessary parameters for the application of the developed equations. Whitehouse and Archard [12] verified that many engineering surfaces had aleatory characteristics, and treated their parameters statisfically. Thomas and Sayles [13] used the statistic theory to analyse the waviness effect on thermal contact resistance. Jones et al. [14] developed a method to calculate the contact parameter from the coupled surface topography. Al-Astrabadi et al. [15] also utilized statistics to study the surface finishing.

2.2. Mathematical models

Some authors stablished mathematical models for their physical models, but only few works arrived to formulations able to be used for the theoretical calculation of the thermal contact resistance. The models developed by Fenech and Rohsenow [5], Clausing and Chao [16], and Mikic and Rohsenow [10] can be utilized to predict this resistance. The Fenech and Rohsenow's model, the first to be developed, has some practical difficulties, like the surface parameters determination, that make its use unfeasible [17]. In this work Clausing's and Mikic and Rohsenow's models are used, described briefly below.

Clausing's model. Figure 3 shows the contact zone between two identical solid cylinder of lenght L and radius b_L. The macroscopic contact area dimension are given by the bodies elastic deformation. The waviness is represented by spherical callotes of radius r_1 and r_2, placed in the top of the cylinders, in the contact zone. The distance between the callotes base and its top (d) corresponds to the waviness height. X_L is the macrocontact area constriction rate ($X_L = a_L/b_L$), where a_L is the mean macrocontact area radius, a_m corresponds to the actual contact points mean radius and b_m its respective cilinder base radius.

For this physical model, Clausing considered that:

(1) L is big in comparison to b_L;

(2) there is perfect contact points through the macrocontact area, in other words, $R_m < < R_L$;

(3) the heat is transferred only through the macrocontact areas;

(4) the opposite cylinders base areas have uniform temperature;

(5) the surface materials are homogeneous, isotropic and their physical properties are constant with the temperature.

Mikic and Rohsenow's model. Mikic and Rohsenow [10], in their physical model, considered the surface contact points round, with mean radius a_m uniformly spread in the macrocontact areas. The macrocontact areas are divided into circles of radius b_m with the elementary cylinders base centered in the contact points as shown in Figure 4. On the other hand, the apparent contact area is divided into circles of radius b_L, centered in the macrocontact areas.

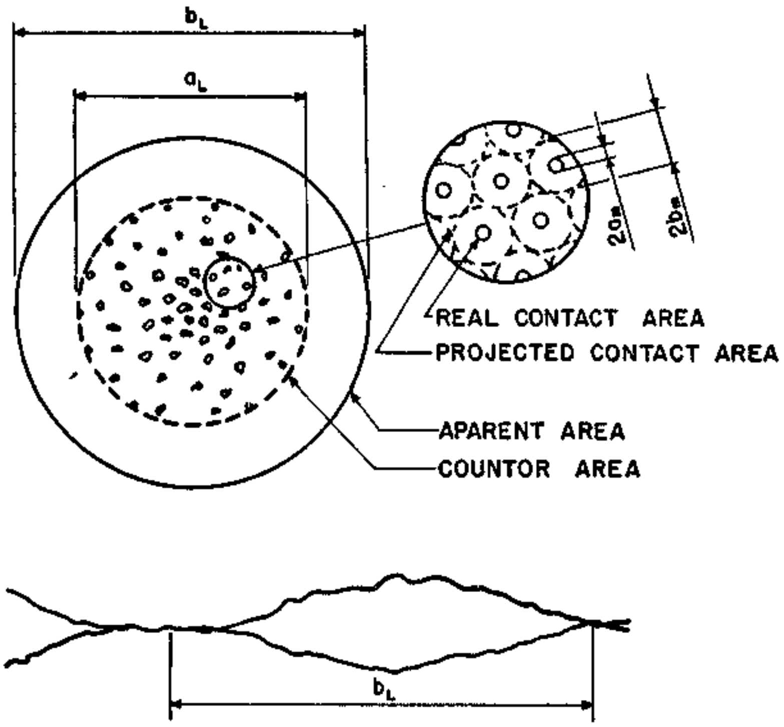

FIGURE 4. Spherical contact physical model.
Source: [10], pp: 29

2.3. Thomas and Probert's Experimental Correlation

For a better understanding of the phenomenon, experimental investigations were performed by some researchers. Thomas and Probert [18], grouped these data and obtained mean curves in an attempt to predict the thermal contact resistance from the mechanical properties and surfaces data. These scientists made the hypothesis that this resistance was affected by the surface hardness, material thermal conductivity and surface roughness, whose units have the following basic dimensions: mass, length, time, temperature and heat. There are three independent equations that relate these parameters and, by the π theorem, can be grouped in $5 - 3 = 2$ dimensionless sets. The aluminum mean curve constructed by Thomas and Probert was made using 240 experimental data. It is important to keep in mind that the unique surface parameter considered was the roughness. The correlation was performed using experimental data from different sources. Analysing these works, it was verified that all the coupling studied were such as found in enginnering, with waviness. Thus the noninclusion of the waviness parameter does not mean that the correlation is valid only for flat surfaces, but that it has mean waviness values inserted in its coefficients. It is difficult to estimate these values, because they result from the combined effects of the wavelength and the waviness maximum height, nevertheless one can expect the correlation to produce good results for mean waviness surfaces. The correlation curves are compared with the Clausing's and Mikic and Rohsenow's theoretical curves in the next section.

2.4. Comparison Between the Three Methods.

The aim of this section is to analyse the methods described above. This is made through the curves behaviour study versus the surface parameters variation, to determine the most convenient method for the thermal resistance calculation of the first Brazilian satellite contacts. In order to get this comparison, the methods were implemented in computer. The program entries are the mechanical and surface properties of the coupled metals and the program output are the three thermal conductance curves as a function of the pressure, all in the same graph. The contacts are made of 2024 aluminum surfaces, and typical surface finishing variations of this material are used for this analysis. To organize this study the curves are grouped according to Tables 1 and 2, where:

(1) BL- wavelength;

(2) DT- maximum waviness height;

(3) RMS - root mean square;

(4) TGTT - tan(θ)

The Clausing's [6], [7], [8] and Mikic and Rohsenow's [10] theories are based on similar physical models. The main difference between them lies in the fact that Mikic and Rohsenow considered the influence of the microcontacts due to the roughness presence. It is expected that the curves are close for smooth (Figures 5.1a, 2.a, 3.a) and distant for rough surfaces (Figures 5.1.c, 2.c, 3.c), where the microconstriction importance grows. For flat surfaces (with small waviness), the distance between these curves is large (Figures 5.2.a, b, c); this effect is specially observed for flat and rough surfaces (Figures 5.2.c). It is interesting to note that the two theoretical curves have almost ever similar curvatures.

The influence of the maximum height variation in the waviness is bigger than the influence of the lenght variation, as it can be observed in Figures 5.5a, b and 6.a,b.

Table 1. Numerical values used in the sets from 1 to 6, as showed in Table 2.

		SMALL	MEDIUM	LARGE
ROUGHNESS PARAMETERS	ROUGHNESS RMS$\times 10^{-6}$ METERS	1.1003	2.1336	7.6200
	ASPERITY ANGLE PEAK TANG. TGTT	0.1200	0.1760	0.2670
WAVINESS PARAMETERS	WAVINESS LENG. BL- $\times 10^{-2}$ m	0.6096	1.2954	1.9812
	MAXIMUM HEIGHT DT-$\times 10^{-6}$ m	3.0480	21.6410	40.2340

Table 2. Curve sets used in the three method comparison.

SET	ROUGHNESS	WAVE LENGTH	MAXIMUM WAVE HEIGTH	ASPERITY ANGLE PEAK
1	VARIABLE	MEDIUM	MEDIUM	SMALL
2	VARIABLE	SMALL	SMALL	SMALL
3	VARIABLE	LARGE	LARGE	SMALL
4	MEDIUM	MEDIUM	MEDIUM	VARIABLE
5	MEDIUM	MEDIUM	VARIABLE	SMALL
6	MEDIUM	VARIABLE	MEDIUM	SMALL

Analysing the experimental correlation behavior, it is verified that its curves are always more distant from the theoretical ones than the theoretical curves are from each other. This correlation estimates smaller conductance values than the other ones, for the same pressure, with exception of Figure 5.1.a and 3.a. The Figure 5.3.a coupling, which

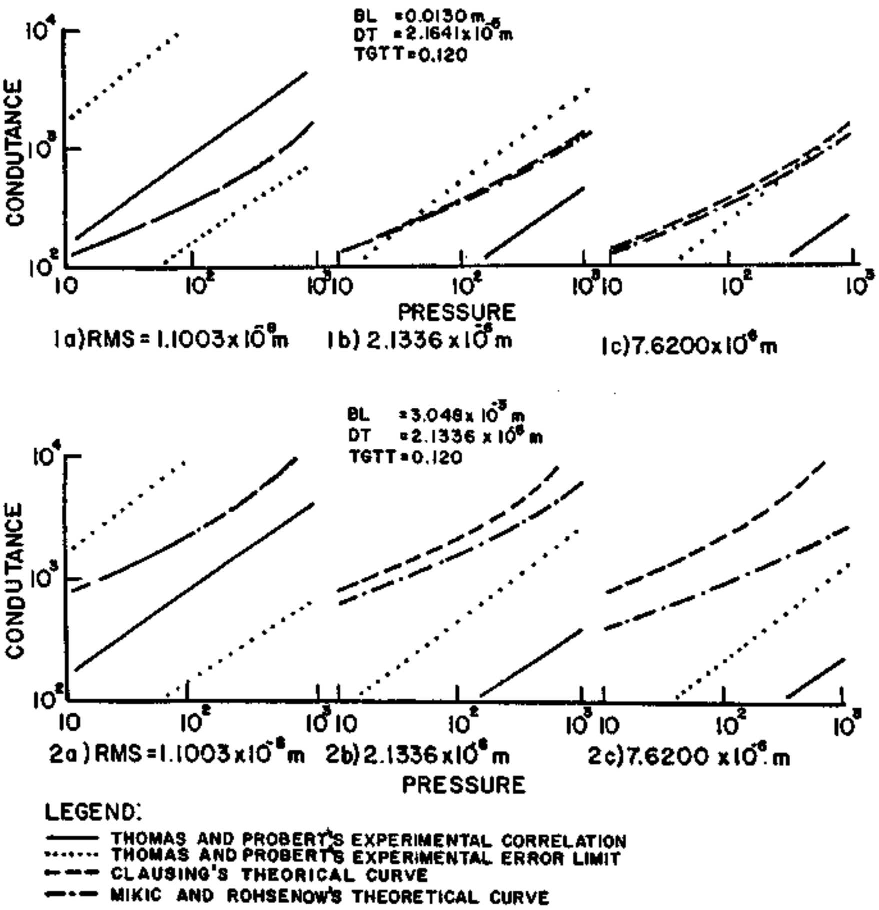

FIGURE 5. Three method comparison curves (first part).

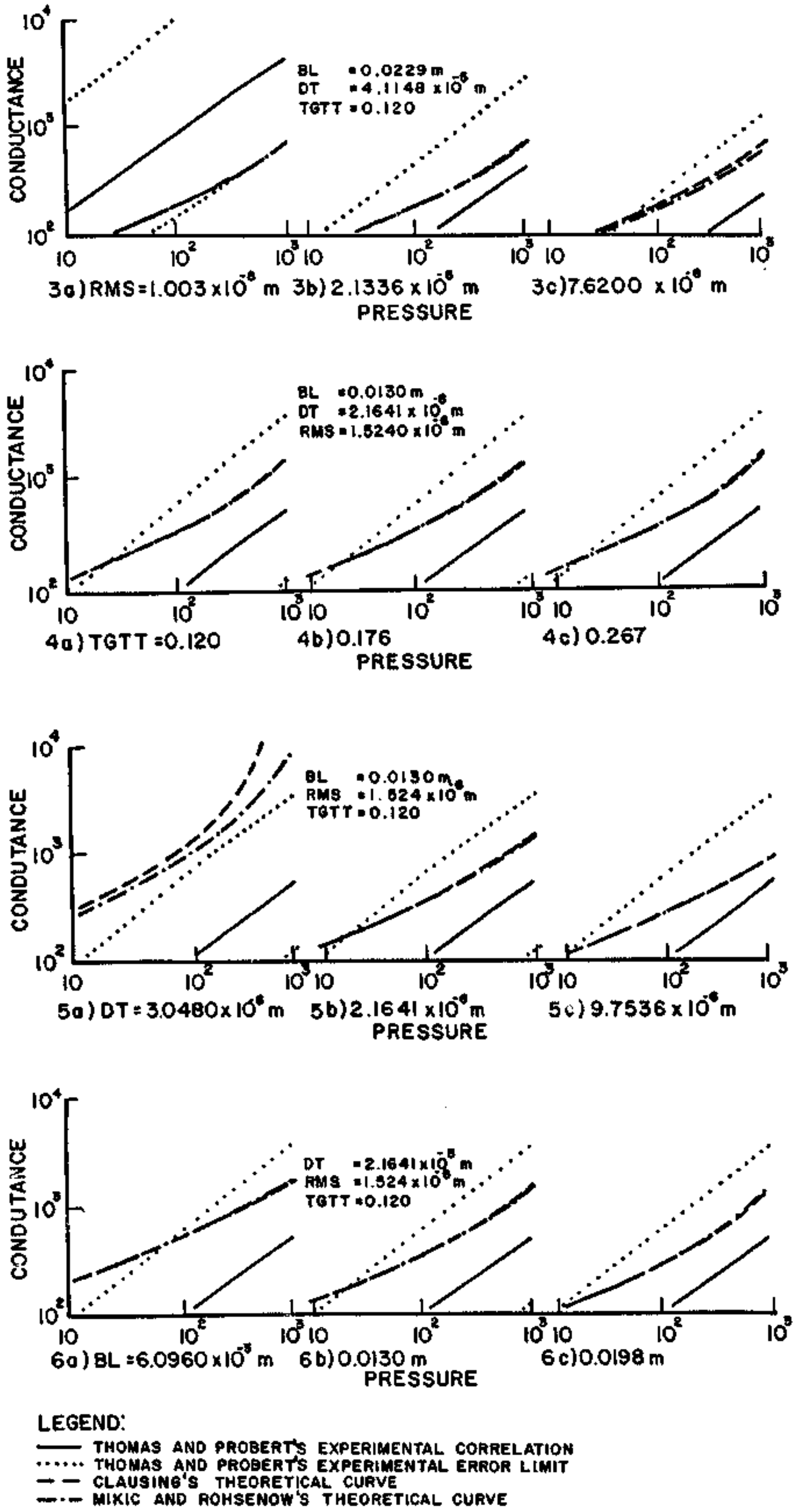

FIGURE 5. Three method comparison curves (second part).

represents contacts between surfaces with large waviness and medium roughness, presents the closest three method curves of all studied; it means that the contact surfaces considered when the correlation was mounted, probably had large waviness.

The asperity peak angle variation actually found, from 150° to 160°, causes a very small variation in the Mikic and Rohsenow's theoretical curve, as it can be seen in Figure 5.4d. In this way, one can use $tg\theta = 0.120$, as suggested by these researchers, since otherwise it would be difficult to get this surface parameter from the contact bodies profile.

Note that for medium wavelength, medium roughness and small maximum waviness height surfaces (see Figure 5.6a), the theoretical curves are distant each from other, with a similar effect as for very rough surfaces. It can be explained by the fact that when the rate b_L/d_t grows, the waviness characterists changes, and the surface became very rough.

From this analysis one can arrive to the following conclusions: -

(1) for the studied contacts, the influence of the macroconstriction on thermal contact resistance is greater than that of microconstriction; this is observed from the fact that the Mikic and Rohsenow's and Clausing's curves have the same curvature and are close each other. It is also important to observe that Mikic and Roshenow's, in their theory, gave the same mathematical treatment to micro and macroconstriction;

(2) as the Mikic and Rohsenow's theory includes both the micro and macroconstriction, it is expected that it reproduces the actual resistance with more precision than the Clausing's theory, witch considers only the macroconstriction. The same is expected, since the correlation just considers the roughness;

(3) the correlation can, for small waviness surfaces, be used as a lower limit for the contact conductance, when it is in favor of the safety factor;

(4) for small rough surface, the Clausing's theory can be used, because both theoretical curves are very close:

(5) the asperity peak angle measurement can be omitted, and $tg\theta = 0.120$ can be assumed as a good mean value for practical use.

Table 3. Coupling surface parameters and physical properties.

COUPL	SURF	ROUG. RMS $\sigma \mu_m$	MAX. HEIG. $d \mu_m$	WAVI. LENG. BL- m	ASPER. ANGLE TANG.	MEAN THER CONDUCT. K W/m°C	HARD. KN/m^2 $\times 10^6$	ELAST KN/m^2 $\times 10^7$
1	1A	1.257	3.810	0.014	0.120	120.230	1.500	6.895
	1B	1.397	2.540	0.014	0.120	120.230	1.500	6.895
2	2A	0.223	6.350	0.019	0.120	120.230	1.500	6.895
	2B	0.223	2.540	0.019	0.120	120.230	1.500	6.895

2.5. The Methods Comparison Applied to Literature Experimental Data

Fried and Kelley [19], using a thermal contact resistance measurement experimental apparatus, projected and built by them, studied, among other, two couplings similar to the contacts found in space applications, formed by 2024 T4 aluminum surfaces , described in Table 3. These searches had the objective of studying the influence of the surface parameters, mechanical properties, and interface pressure. The Brazilian satellite contacts considered are made of 2024 T351 surfaces, with mechanical properties very similar to the 2024 T4 ones. Then the couplings showed in Table 3 are similar to the satellite ones, so that from the fried and Kelley's experimental results and the theoretical curves comparative study it is possible to indicate the most suitable method for the thermal contact resistance calculation of the Brazilian satellite.

Figure 6 shows the graphics used for comparison between the experimental data and theoretical curves for each coupling. Analysing this figures, it is seen that most of experimental points are closer to the theoretical clausing's and Mikic and Rohsenow's curves than to the experimental correlations. It is even noticeable that the correlation describes in a better way the less rough coupling (number 2) (Figure 6), according to the last section observations. Since the experimental points are more distant from the correlation curves than from the theoretical ones, the nonutilization of the experimental correlation is justified. The question that now arises is to verify which of the two theoretical method is the most suitable for the calculation of thermal contact resistance of these satellite couplings.

There is no doubt that the experimental points are nearer to Mikic and Rohsenow's than to Clausing's curves for the coupling number 1, But this is not so clear for the coupling number 2, where at the right sight it could be seen that the Clausing's curve is the best one. But joining all the experimental points, it is easily observed that, in average, the Mikic and Rohsenow's is the most fitted theoretical curve.

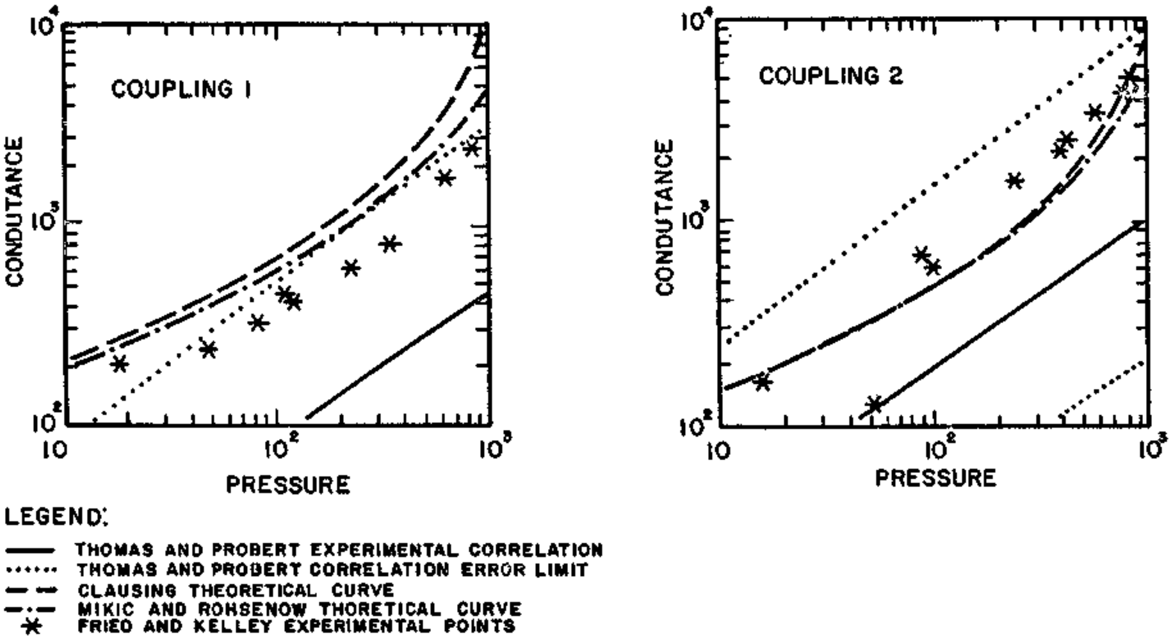

Figure 6. Fried and Kelley experimental data and theoretical curves.

Therefore, it can be concluded that for the Fried and Kelley's couplings, the Mikic and Rohsenow's proposed model is the most suitable for the experimental points, and as the satellite couplings are similar to these ones, it is recommended to use the Mikic and Rohsenow's theoretical curve for the calculation of the satellite thermal contact resistances.

3. CONCLUSION

The main conclusion is that the model developed by Mikic and Rohsenow [10] was the most indicated because it considers the heat flux macro and microconstriction influence. It is important to note that this method has given good results in spite of the fact that it was found some difficulties to find up to date literature, where new and most appropriate experimental correlations were obtained. It is suggested to repeat this procedure using new literature methods.

From the comparative analysis, it could be concluded mainly that:

(1) the heat flux macroconstriction influence is greater than the microconstriction;

(2) the asperity peak angle determination is not necessary, and the literature suggested value can be used without problems.

As this work analysed only one kind of aluminum couplings, it would be necessary to repeat this same procedure to qualify this method for a more general use.

NOMENCLATURE

a	microcontact area mean radius;
A	apparent contact area;
b	elementar cylinder mean radius;
d	maximum waviness radius;
D	unit cylinder diameter;
h	thermal contact conductance;
L	unit cylinder height;
P	contact pressure;
Q	heat flux;
r	spherical callote radius, simulating the ondulations;
R	thermal resistance;
T	temperature;
X	heat flux positive direction;
x_L	macrocontact constriction rate;
z	perpendicular direction to the contact surfaces;
δ	roughness mean height;
θ	asperity angle peak;
σ	rms roughness;

Inferior index

L	macrocontacts;
m	microcontacts;
1	coupling surface number 1;
2	coupling surface number 2;

REFERENCES

1. Brunot, A.W., Buckland, F.F., Thermal Contact Resistance of Laminated and Machined Joints, *Transactions of ASME*, pp:253-256, 1948.

2. Barzelay, M.E., Tong, K.N., Holloway, G.F., Thermal Conductance of Contacts in Aircraft Joints, Washington, D.C., National Advisory Comittes for Aeronautics, 1954, (NACA Technical Note 3167).

3. Barzelay, M.E., Tong, K.N., Holloway, G.F., Effect of Pressure on Thermal Contact Resistance of Contact Joints, Washington, D.C., National Advisory Committee for Aeronautics, 1954, (NACA Technical Note 3167).

4. Fried, F., Costello, F.A., Interface Contact Resistance Problems in Space Vehicles, *ARS Journal*, vol.32, nº 2, pp:237-243, 1962.

5. Fenech, H., Rohsenow, W.M., Prediction of Thermal Conductance of Metallic Surfaces in Contact, *Journal of Heat Transfer*, vol. 85, nº 4 pp:15-24, 1963.

6. Clausing, A.M., An Experimental and Theoretical Investigation of the Thermal Contact Resistance, Urbana, Il., University of Illinois, 1966, (M.E. Technical Report nº 242-2).

7. Clausing, A.M. Heat Transfer at the Interface of Dissimilar Metals - the Influence of Thermal Strain, *International Journal of Heat and Mass Transfer*, vol.9, nº 8, pp:791-801, 1966.

8. Clausing, A.M., Theoretical and Experimental Study of Thermal Contact Resistance in Vaccum Environment, Urbana, Il., University of Illinois, 1966.

9. Timoshenko, S.P., Goodyear, J.N., *Theory of Elasticity*, 3d. ed., Mc-Graw Hill Kogakusha, Tokio, Japan, 1970.

10. Mikic, B.B., Rohsenow, W.M, Thermal Contact Resistance, Cambridge, M.T., MIT, 1966, (MIT Technical Report nº 4542-41).

11. Yovanovich, M.M., Rohsenow, W.M., Influence of Surface Roughness and Waviness upon Thermal Contact Resistance, Cambridge, M.T., MIT, 107 (MIT Technical Report nº 6361-48), 1967.

12. Whitehouse, D.J., Archard, J.F., The Properties of Random Surface of Significance in their Contact, *Proc. Royal Society of London*, 316-A, pp:97-121, 1970.

13. Thomas, T.R., Sayles, R.S., Random Process Analysis of the Effect of Waviness on Thermal Contact Resistance, *AIAA/ASME Thermophysics and Heat Transfer Conference, Boston*, MA., July 15-17 (AIAA Paper nº 74.691).

14. Jones, A.M., O'Callaghan, P.W., Probert, S.D., Prediction of Contact Parameters from the Topographies of Contacting Surfaces, *Wear*, vol.31, pp:89-107, 1975.

15. Al.Astrabadi, F.R., O'Callaghan, P.W., Probert, S.D., Effects of Surface Finish on Thermal Contact Resistance Between Different Materials, *AIAA Thermophysics Conference, Orlando, Fl.*, vol.14, June 4-6, 1979.

16. Clausing, A.M., Chao, B.T., Thermal Contact Resistance in a Vacuum Environment, *Journal of Heat Transfer*, vol.85, nº 4, pp:15-24, 1963.

17. Chen, M.S.H., Mantelli, M.B.H., Oliveira Filho, O.B., Estabelecimento de um Procedimento para Determinação de Parâmetros Necessários ao Cálculo da Resistência Térmica de Contactos no Interior de Satélites, São José dos Campos, INPE, Out 1985, (INPE-3690-RPE 1492).

18. Thomas, T.R., Probert, S.D., Correlations for Thermal Contact Conductance in Vacuum, *Journal of Heat and Mass Transfer*, vol.13, pp:789-807, 1970.

19. Fried, F., Kelley, M.J., Thermal Conductance of Metallic Contacts in a Vacuum, *AIAA Thermophysics Specialists Conference*, Monterey, CA., Sept 13-15, 1965. (AIAA Paper 65-661).

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