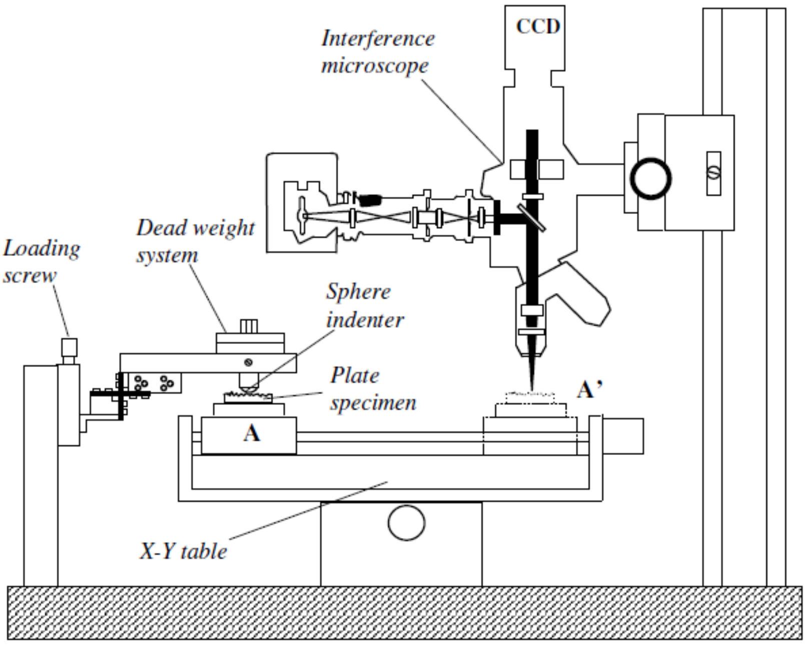
APPENDIX

a) Detail of Experimental Setup

Experiment validation in this thesis is obtained from work of Jamari (Jamari, J., 2006, Running-in of Rolling Contacts, Ph.D. Thesis, University of Tweente, Faculty of Engineering Technology). The detail explaination on how Jamari worked with his experiment is described below:

The matching and stitching procedure (see Sub-section 3.5.1 and Appendix C) is utilized in these experiments. Experiments were performed on a setup as shown in Fig. 4.4. The maximum load which could be applied to this setup was about 30 N. Before doing any test, the spherical and flat specimens were cleaned with acetone and dried in air.



An optical interference microscope was used to measure the three-dimensional surface roughness. An X-Y table which is controlled by stepper motors was employed to position the flat specimen from the loading position (position **A**) to the surface measuring position (position **A'**) and the other way around. The measurement sequence is as follows. First, the flat surface was measured under the optical interference microscope. The number of the stitching images which should be taken depends on the predicted contact area and the chosen magnification of the interferometer. After finishing the surface measurement in position **A'** the flat surface was moved to the loading position **A**. In this loading position the statically mounted sphere specimen was moved down by the loading screw and subsequently loaded by the dead weight load system. To reduce the effect of friction, the contact region was lubricated. The load was applied to the sphere specimen for 30 seconds and then unloaded. Prior to measuring the after loading contact area with the optical interference microscope, again the spherical and flat specimens were cleaned and dried. After taking all the surface images data, the matching and stitching calculation was performed separately by a personal computer.

b) Photographic Impression of the Experimental Equipment

Pictures presented in this page are obtained from work of Jamari (Jamari, J., 2006, Running-in of Rolling Contacts, Ph.D. Thesis, University of Tweente, Faculty of Engineering Technology). It explaining real condition of instrument used during experiment.

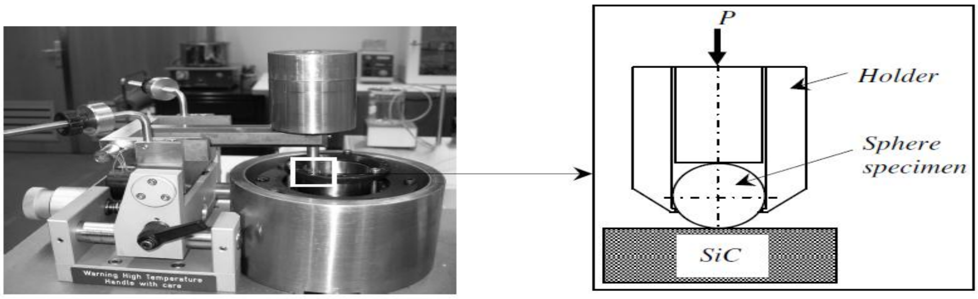


FIGURE D.1: *Pin-on-disk machine.*

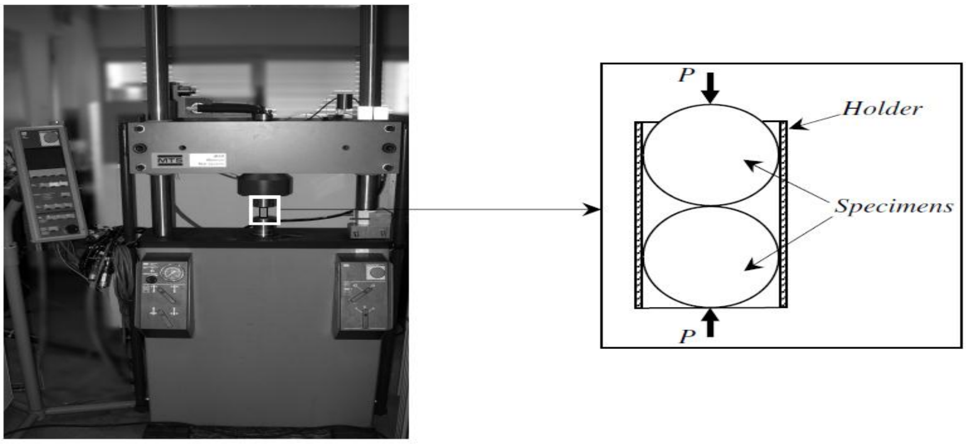


FIGURE D.2: *Tensile testing machine.*

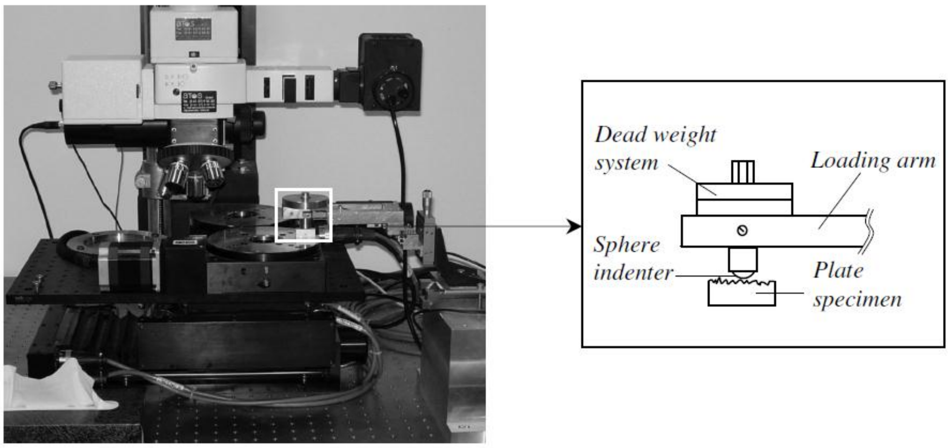


FIGURE D.3: *Static indentation (x-y table) setup.*

c) Asperities Determination of Real Rough Surface

Analytical validation in this thesis is obtained from work of Jamari (Jamari, J., 2006, Running-in of Rolling Contacts, Ph.D. Thesis, University of Tweente, Faculty of Engineering Technology). The detail explaination on how Jamari calculate his work is presented below:

A method to model the micro-contacts of real rough surfaces by elliptical paraboloids will be described in this appendix. The model is based on a volume conservation method.

An elliptical paraboloid is defined as a paraboloid having an elliptical cross-section in the *xy*-plane and paraboloids in the *xz*- and the *yz*-plane respectively. In a mathematical form, this elliptical paraboloid is expressed by [F1]:

$$\frac{x^2}{a^2}+\frac{y^2}{b^2}-\frac{z}{c}=0 \tag{F.1}$$

where x, y, and z are the coordinate system and a, b, c are constants. The volume displaced, V, due to contact of this elliptical paraboloid is the same as the volume above a certain cut-off height (volume conservation), hence:

$$V=\int_{x_{low}}^{x_{high}}\int_{y_{low}}^{y_{high}}\int_{z_{low}}^{z_{high}} dxdydz \tag{F.2}$$

The limits of integral in Eq. (F.2) are determined as follows. For the z-coordinate, the upper integration limit is the cut-off height ω of the micro-contact as:

$$z_{low}=\omega \tag{F.3}$$

and the lower limit is determined rearranging Eq. (F.1) into:

$$z_{high}=\frac{c}{a^2b^2}\left(x^2b^2+y^2a^2\right) \tag{F.4}$$

For the y- coordinate, the following equations are valid at the edge of the contact:

$$\frac{c}{a^2b^2}\left(x^2b^2+y^2a^2\right)=\omega \tag{F.5}$$

and by solving y in Eq. (F.5) gives:

$$y_{low}=-\frac{b}{ac}\sqrt{c\left(a^2\omega-cx^2\right)} \tag{F.6}$$

$$y_{high}=\frac{b}{ac}\sqrt{c\left(a^2\omega-cx^2\right)} \tag{F.7}$$

Now, the integration limits for x are left to consider. These can be determined by substituting $y_{low} = y_{high} = 0$ into Eqs. (F.6) and (F.7) which results:

$$x_{low} = -a\sqrt{\frac{\omega}{c}} \tag{F.8}$$

$$x_{high} = a\sqrt{\frac{\omega}{c}} \tag{F.9}$$

By substituting Eqs. (F.3) – (F.9) into Eq. (F.2) prior to integration and simplifying yields:

$$V = \frac{\pi}{2}\frac{ba}{c}\omega^2 \tag{F.10}$$

The length of the micro-contact area in x-direction L_x is calculated by subtracting Eq. (F.9) by Eq. (F.8) as:

$$L_x = 2a\sqrt{\frac{\omega}{c}} \tag{F.11}$$

and the length of the micro-contact area in y-direction L_y is calculated by subtracting Eq. (F.7) by Eq. (F.6) at $x = 0$ as:

$$L_y = 2\frac{b}{ac}\sqrt{ca^2\omega} \tag{F.12}$$

Substituting Eqs. (F.11) and (F.12) into Eq. (F.10) results into a new expression for the volume as:

$$V = \frac{1}{8}\pi L_x L_y \omega \tag{F.13}$$

Curvature is defined as the second derivative of the elliptical paraboloid, thus the curvature κ_x in x-direction and the curvature κ_y in y-direction are found by applying the second derivative to Eq. (F.1) as:

$$\kappa_x = \frac{2}{a^2} c \tag{F.14}$$

$$\kappa_y = \frac{2}{b^2} c \tag{F.15}$$

A combination is made by rearranging Eqs. (F.10) – (F.15):

$$\sqrt{\kappa_x \kappa_y} = 2\frac{c}{ab} = \frac{8\omega}{L_x L_y} = 4\pi \frac{V}{A^2} \tag{F.16}$$

$$\frac{\kappa_x}{\kappa_y} = \frac{L_y^2}{L_x^2} \tag{F.17}$$

Substituting Eq. (F.17) into Eq. (F.16) and rearranging gives the final expressions for the elliptic paraboloid that will be used for 'fitting' the real micro-contact region as:

$$\kappa_x = 4\pi \frac{V}{A^2} \frac{L_y}{L_x} \tag{F.18}$$

$$\kappa_y = \kappa_x \frac{L_x^2}{L_y^2} \tag{F.19}$$

d) Surface Roughness Values from Various Machining Processes

As explained in second chapter that surface roughness are formed from manufacturing process. The table below (Rochim, T., 2001, “Spesifikasi metrology & control kualitas geometric 1, Penerbit ITB, Bandung) give information about the roughness created on each machining process.

Manufacturing method		Achievable peak-to-valley height, R_t (μm) ♥																						
Main group	Type:	0.04	0.06	0.1	0.16	0.25	0.4	0.63	1	1.6	2.5	4	6.3	10	16	25	40	63	100	160	250	400	630	1000
Creative Forming	Sand casting															S	S	N	N	N	N	R	R	R
	Shell molding															S	S	N	N	N	R			
	Die casting													S	S	N	N	N	N	N	R			
Reforming	Forging													S	S	S	S	N	N	N	N	N	R	R
	Plain rolling				S	S	S	S	N	N	N	N	R	R										
	Drawing							S	S	S	S	N	N	N	R									
	Pressing												S	S	S	N	N	N	N	R	R			
	Stamping											S	S	N	N	R								
	Section rolling										S	S	S	N	N	N	N	R	R					
Machining	Cutting													N	N	N	N	N						
	Longitudinal turning									S	S	N	N	N	N	N	N	N	R	R				
	Face turning											S	S	N	N	N	N	N	R	R				
	Recessing											S	S	N	N	N	N	R	R					
	Planing								S	S	S	N	N	N	N	N	N	N	R	R	R			
	Slotting										S	S	S	N	N	N	N	R	R					
	Shaving									S	S	S	N	N	N	N	R							
	Drilling														S	S	N	N	N	N	R			
	Boring					S	S	S	S	S	N	N	N	N	N	R	R							
	Counter-sinking/boring												S	N	N	N	R							
	Reaming							S	S	S	S	N	N	N	R	R								
	Circumferential milling										S	S	S	N	N	N	N	R	R	R				
	End milling										S	S	S	N	N	N	N	R	R	R				
	Broaching								S	S	N	N	N	N	N	R	R							
	Filing										S	S	N	N	N	N	N	N	R	R				
	Plain, longitudinal grinding					S	S	S	S	N	N	N	R	R	R									
	Plain, surface grinding									N	N	N	N	N										
	Plain, plunge grinding							S	S	N	N	N	R	R										
	Circumferential grinding								S	S	N	N	N	R	R	R								
	Face grinding								S	S	N	N	N	R	R	R								
Polishing	Polishing			S	S	S	N	N	N	R	R													
	Tumbling						N	N	N															
	Long-stroke honing		S	S	S	S	S	S	N	N	N	N	R											
	Short-stroke honing	S	S	N	N	N	N	N	N	R	R													
	Cylindrical lapping	S	S	S	N	N	N	N	N	N	R	R	R											
	Surface lapping	S	S	S	S	N	N	N	N	N	R	R	R											
	Lapping in																							
	Liquid honing				N	N	N	N	N	N	N													
	Polish lapping	N	N	N	N	N	R																	
Others	Blasting													S	N	N	N	N	R	R	R			
	Barreling					N	N	N	N															
	Flame cutting														S	S	N	N	N	R	R	R	R	

♥ S: normally smooth ; N: normal ; R: normally rough.

TEKNIK PRODUKSI, MESIN, FTI-ITB