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Correction of squareness measurements of Vickers indenters due to the tilt of the pyramid axis

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Abstract. In Vickers hardness measurements, ISO 6507-2 and 6507-3 Standards require to verify that the quadrilateral of the pyramid indenter base has angles of 90° ± 0.2°. Such measurement is usually performed through optical measuring systems, which, rotating the diamond indenter, allows to evaluate the angles between two consecutive faces with high accuracy. These angles correspond to the angles of the quadrilateral base when the axis of the pyramid is perfectly perpendicular to the seating surface. Nevertheless, when the pyramid axis is tilted, the angles between two consecutive faces are different from the corresponding angles on the quadrilateral base, thus a correction is required. In this work, a method to correct squareness measurements, based on a geometrical model, is presented.

1. Introduction

The influence of Vickers diamond indenters geometry in hardness measurements is very well known and it has been deeply investigated [1,2]. Reference ISO 6507-2 and 6507-3 Standards [3,4] specify the requirements of the diamond pyramid indenter. In particular, it shall be verified that the quadrilateral of the pyramid indenter base, which would be formed by the intersection of the faces with a plane perpendicular to the axis of the diamond pyramid, has angles of 90° ± 0.2°, and that the angle between the axis of the diamond pyramid and the axis of the indenter-holder (normal to the seating surface), i.e. the tilt of the pyramid axis, shall be less than 0.3°. Nevertheless possible influences of the tilt of the pyramid axis on the measurement of the angles of squareness are completely missing. In fact, given a pyramid with a tilted axis with respect to the indenter-holder axis, the angles between two consecutive faces are different from the angles of the quadrilateral base on which the pyramid leans. Such behaviour has important effects on the measurement of squareness, thus a correction method, that compensates the effect of the tilt of the pyramid axis, is needed and presented in this work.

2. Squareness measurements of the pyramid indenter quadrilateral base

Measurements of the angles φ_i of the quadrilateral intersection between the faces and a plane perpendicular to the axis of the Vickers diamond pyramidal indenter are usually performed by means of an optical measuring system based on microscopes using confocal technology and equipped with an angular encoder, which allows to rotate the diamond indenter around the axis of the indenter-holder until a lateral face is perfectly parallel to the lens of the system. This is verified observing the interference fringes on the microscope [5]. INRiM hardness laboratory uses the GALILEO-LTF Gal-

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Indent optical system which is composed of an interferometric sine-bar system able to measure the vertex angle α of the Vickers indenters (nominally 136°) and the angles γ_i between two consecutive faces (nominally 90°) with high accuracy [6]. The latter correspond to the angles φ_i of the quadrilateral base when the axis of the pyramid is perfectly perpendicular to the horizontal plane of the seating surface. Nevertheless, when the pyramid axis is tilted by an angle β, the angles γ_i between two consecutive faces are different from the corresponding angles φ_i on the quadrilateral base, as shown in figure 1, thus a correction is needed.

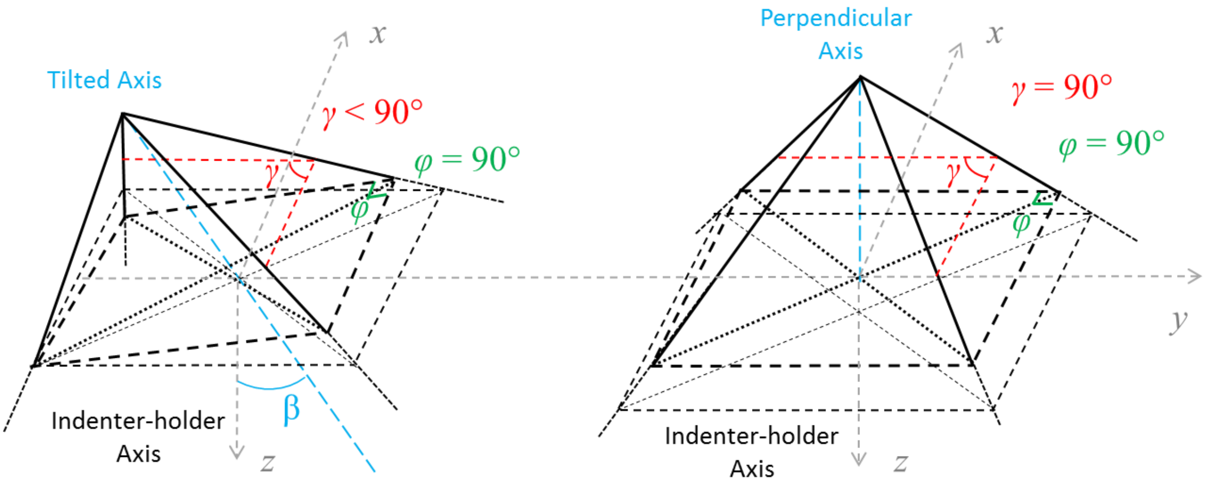

Figure 1. The geometry of a generic pyramid with a tilted axis (left) and with a perpendicular axis (right).

3. Correction method

The geometry of the angles of the indenter measured with the optical system is given in figure 2.

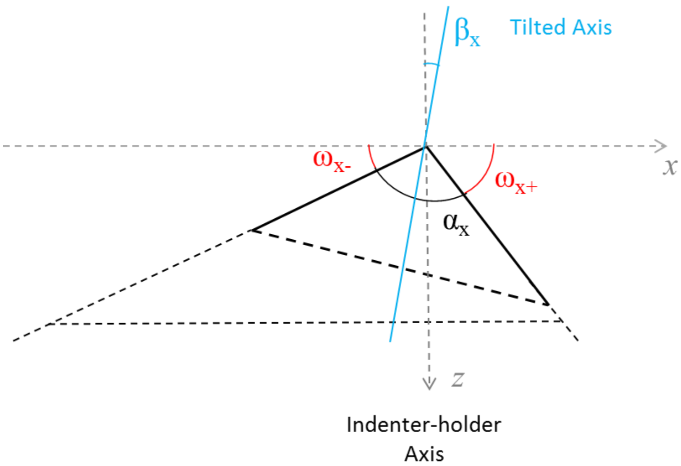

Figure 2. Measured angles in the XZ plane of the Vickers indenter with the optical system.

From the optical measuring systems it is possible to measure the two vertex angles α_x ands α_y of the indenter along x- and y- axis (nominally 136°), their complementary angles in both clockwise and anticlockwise directions (ω_{x-}, ω_{x+}, ω_{y-}, ω_{y+}) and the angles $\gamma_{exp,i=1,2,3,4}$ between two consecutive lateral faces, which should correspond to the angles φ_i of the quadrilateral base in case of right pyramid. The tilt of the axis β_x and β_y along x- and y- axis respectively, can be evaluated according to equation (1).

IOP Conf. Series: Journal of Physics: Conf. Series **1065** (2018) 062005 doi:10.1088/1742-6596/1065/6/062005

$$\beta_x = \frac{\omega_{x+} - \omega_{x-}}{2}; \quad \beta_y = \frac{\omega_{y+} - \omega_{y-}}{2} \tag{1}$$

Supposing to cut the pyramid with a horizontal plane of equation z=1 parallel to the XY plane, it is possible to define the vectors **v** and $\mathbf{p}_{i=1,2,3,4}$ which represent the vectors of the pyramid axis and of the four lateral edges, as shown in equation (2).

$$\begin{cases} \mathbf{v} = (v_x; v_y; v_z) = \left(\tan\frac{\beta_x}{2}; \tan\frac{\beta_y}{2}; 1\right) \\ \mathbf{p_1} = (p_{1x}; p_{1y}; p_{1z}) = \left(\tan\frac{\alpha_x}{2}; -\tan\frac{\alpha_y}{2}; 1\right) \\ \mathbf{p_2} = (p_{2x}; p_{2y}; p_{2z}) = \left(\tan\frac{\alpha_x}{2}; \tan\frac{\alpha_y}{2}; 1\right) \\ \mathbf{p_3} = (p_{3x}; p_{3y}; p_{3z}) = \left(-\tan\frac{\alpha_x}{2}; \tan\frac{\alpha_y}{2}; 1\right) \\ \mathbf{p_4} = (p_{4x}; p_{4y}; p_{4z}) = \left(-\tan\frac{\alpha_x}{2}; -\tan\frac{\alpha_y}{2}; 1\right) \end{cases} \tag{2}$$

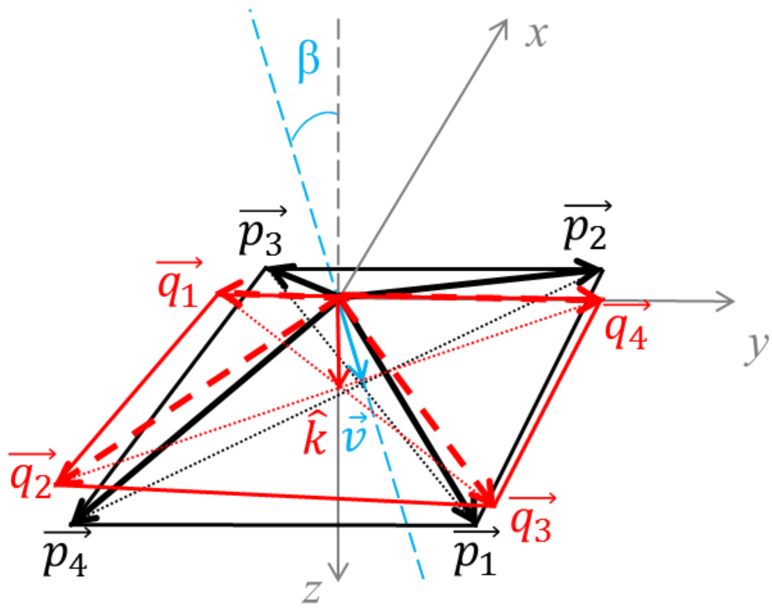

Figure 3. Geometry of the real indenter (black) and the corrected indenter (red).

With such geometry it is possible to straighten the pyramidal Vickers indenter by finding the symmetrical lateral edge vectors $\mathbf{q}_{i=1,2,3,4}$ with respect to the bisector of the tilt angle of the pyramid axis, according to equation (3) and figure 3.

$$\mathbf{q_i} = \left(\frac{2\left(\vec{p_i}\cdot\frac{\vec{v}}{\|\vec{v}\|}\right)\frac{\vec{v_x}}{\|\vec{v}\|} - p_{ix}}{2\left(\vec{p_i}\cdot\frac{\vec{v}}{\|\vec{v}\|}\right)\frac{\vec{v_z}}{\|\vec{v}\|} - p_{iz}}; \frac{2\left(\vec{p_i}\cdot\frac{\vec{v}}{\|\vec{v}\|}\right)\frac{\vec{v_y}}{\|\vec{v}\|} - p_{iy}}{2\left(\vec{p_i}\cdot\frac{\vec{v}}{\|\vec{v}\|}\right)\frac{\vec{v_z}}{\|\vec{v}\|} - p_{iz}}; 1 \right) = \left(\frac{2(\vec{p_i}\cdot\vec{v})\vec{v_x} - p_{ix}\|\vec{v}\|^2}{2(\vec{p_i}\cdot\vec{v}) - \|\vec{v}\|^2}; \frac{2(\vec{p_i}\cdot\vec{v})\vec{v_y} - p_{iy}\|\vec{v}\|^2}{2(\vec{p_i}\cdot\vec{v}) - \|\vec{v}\|^2}; 1 \right) \tag{3}$$

In this way, the nominal angles $\gamma_{i=1,2,3}$ and γ_4 between two consecutive faces of a square base pyramid with a tilted axis can be found according to equation (4) and (5) respectively.

$$\gamma_i = \left\{ \tan^{-1}\left(\frac{q_{i,y} - q_{i+1,y}}{q_{i,x} - q_{i+1,x}}\right) + k_i - \left[\tan^{-1}\left(\frac{q_{i+1,y} - q_{i+2,y}}{q_{i+1,x} - q_{i+2,x}}\right) + k_{i+1} + l_{i+1} \right] \right\} \cdot \frac{180}{\pi} \tag{4}$$

Where $q_{i+2}=q_1$ if i=3; k_i=0 if $(q_{i,x}-q_{i+1,x})>0$, +π if $(q_{i,x}-q_{i+1,x})<0$ and $(q_{i,y}-q_{i+1,y})>0$, -π if $(q_{i,x}-q_{i+1,x})<0$ and $(q_{i,y}-q_{i+1,y})<0$; k_{i+1}=0 if $(q_{i+1,x}-q_{i+2,x})>0$, +π if $(q_{i+1,x}-q_{i+2,x})<0$ and $(q_{i+1,y}-q_{i+2,y})>0$, -π if $(q_{i+1,x}-q_{i+2,x})<0$ and $(q_{i+1,y}-q_{i+2,y})<0$; $l_{i+1}=-k_{i+1}$ if i=1, l_{i+1}=0 if i=2, and $l_{i+1}=-\pi$ if i=3.

$$\gamma_4 = 360 - \gamma_1 - \gamma_2 - \gamma_3 \tag{5}$$

Finally, the measured angles $\gamma_{exp,i=1,2,3,4}$ can be corrected in order to accurately evaluate the angles φ_i of the quadrilateral base according to equation (6).

$$\varphi_i = 90 + \gamma_{exp,i} - \gamma'_i \tag{6}$$

4. Conclusions

Squareness measurements of pyramidal Vickers indenters are usually performed through optical systems by measuring the angles between two consecutive lateral faces. Nevertheless this method is not accurate enough when the pyramidal indenter axis is tilted with respect to the indenter-holder axis by a maximum of 0.3°, as allowed by the Standards. In this case, the angles of the quadrilateral base do not correspond to the angles between two consecutive faces. In this work, such effects and a correction method are presented together with a proper geometrical model.

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