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Modification of Drill Point for Reducing Thrust[1]

S. FUJII[2] AND M. F. DEVRIES.[3] The writers are pleased to see the contribution of Prof. Bhattacharyya, et al., in their paper on the reduction of drill thrust through a modification of drill point geometry. The fifty percent reduction in thrust brought about through the drill point modification can be a significant influence affecting drill performance. Various chisel edge shape modifications have been previously reported and the method presented by the authors may be yet another promising technique. In most prior investigations the experimental results were not accompanied with an analysis that clarified or demonstrated the reason(s) for the improvement in drill performance. This was not a shortcoming of this paper as the authors presented analytical work in an attempt to analyze the geometry of the modified drill in order to develop optimum drill point grinding angles. However, the writers feel that the analysis and its presentation requires more careful considerations than those that were presented by the authors in their paper.

The review of the analysis of the modified chisel edge led us to assume that the authors based their work on the following assumptions which are not mentioned in their paper:

1 The modified chisel edge lies on a plane, P_o, which is perpendicular to the drill axis and contains the dead center of the drill.

2 The modified chisel edge is a circle; that is, the intersection between the cylinder (generated by the grinding wheel periphery) and the drill flank is a portion of a circle.

3 Intersections of the cylinder cut by planes perpendicular to the drill axis (i.e., planes parallel to plane P_o) are always circles irrespective of the cylinder axis orientation; that is to say, irrespective of the values of $\bar{\theta}$ and $\bar{\gamma}$.

The first assumption will yield a reasonable approximation of the shape of the modified chisel edge as long as the modified and original chisel edges are quite similar which would occur if r is large. However, the second and third assumptions are rather crude if $\bar{\theta}$ and $\bar{\gamma}$ are not zero and if indeed they are as large as shown in Fig. 2 of the paper. Hence, the equations derived are not reliable. Equation (1) in the paper contains mistakes even if the three assumptions listed above were valid. It should also be noted that equation (1) is valid only if $\bar{\theta}$ and $\bar{\gamma}$ are zero.

The authors' Fig. 3, from which their equation (1) is developed, does not accurately represent the situation they describe especially

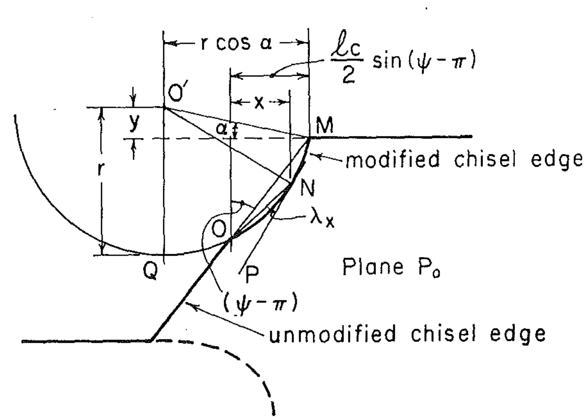

Fig. 15 Revised Fig. 1 showing the geometry of the inclination angle

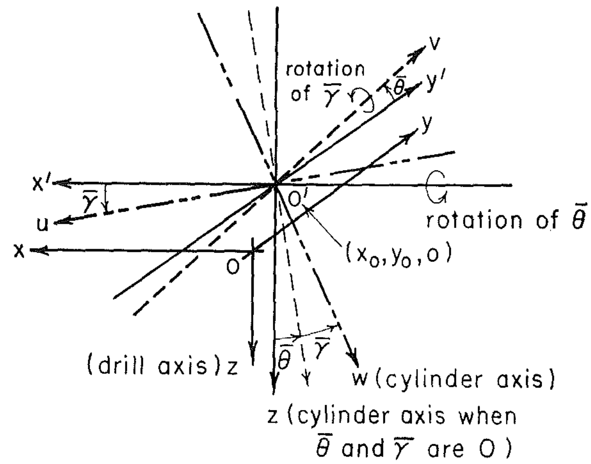

Fig. 16 Relationship between the coordinate systems (x, y, z) and (u, v, w)

with respect to the way in which r is measured. We propose a corrected figure as shown in Fig. 15. On the basis of Fig. 15 the corrected equation (1) should read:

$$\lambda_x = -\frac{1}{2}\left[\sin^{-1}\left(\frac{r\cos\alpha - \frac{l_c}{2}\sin(\psi-\pi) + x}{r}\right) + \sin^{-1}\left(\frac{r\cos\alpha - \frac{l_c}{2}\sin(\psi-\pi)}{r}\right)\right] \quad (15)$$

where

$$\sin\alpha = y/r,$$

and y satisfies the following equation:

$$y^2 + yl_c\cos(\psi-\pi)\cos 2(\psi-\pi) + \frac{l_c^2}{4}\cos^2(\psi-\pi) - r^2\sin^2 2(\psi-\pi) = 0$$

The derivation of y is based on the assumption that the modified chisel edge passes through the drill dead center and the chisel edge corner M as shown in Fig. 15. Thus, the position of the intersection point O' between the cylinder axis and plane P_o is specified as soon as the value of r is given.

The writers would also like to make the following comments about the authors' Fig. 4:

1 A value for the magnitude of r should be given as r is a term contained in Equation (1).

[1] By A. Bhattacharyya, et al., published in the November, 1971, issue of the JOURNAL OF ENGINEERING FOR INDUSTRY, TRANS. ASME, Series B, Vol. 93, No. 4, pp. 1073–1078.

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2 The inclination angle λ of the modified chisel edge at the dead center point O, i.e., $\frac{r_x}{R} = 0$ should be zero as mentioned in the paper and not the 10 deg shown in Fig. 4. The inclination angle of the conventional chisel edge angle should also be 0 deg at the dead center.

3 If the inclination angles were measured from the drills that were ground, it would be of interest to show the comparison between the measured values and those calculated from equation (1). (This same comment applies to the authors' Figs. 7 and 8.)

The definition of l following equation (3) is confusing and may not be correct. It appears from inspection of equation (3) that l is not measured in the direction of the cylinder axis but rather in the direction of the drill axis.

The preceding comments were made assuming that the authors' analysis is based on the three assumptions cited. It appears to us that the second and third assumptions should be discarded. The derivations for the inclination angle λ_x and the normal rake angle γ_n that follow are based upon the first assumption cited above. An approach to obtain these angles without the first assumption is then outlined. It should be noted that the definition of the chisel edge angle ψ in Fig. 1 is not the commonly accepted one and the writers have chosen to use in our derivation the more common definition, i.e., our ψ equals the ψ of Fig. 1 minus $\pi/2$.

We begin our derivation by defining a right hand ordinate system (x, y, z) which is shown in [7][4]:

1 The z-axis is the drill axis with the positive direction toward the drill shank.

2 The y-axis is a perpendicular common to the extensions of the two cutting edges and the z-axis.

3 The x-axis is perpendicular to the y- and z-axes. This coordinate system is then translated in the z direction so that the dead center of the drill point lies on the $z = 0$ plane with this new coordinate system renamed as the coordinate system (x, y, z). The amount of this translation is given as f_o in reference [9]. Thus, the modified chisel edge also lies on the new $z = 0$ plane.

Assume further that the axis of the hypothetical cylinder, generated by the grinding wheel periphery, intersects the $z = 0$ plane at a point O' having coordinates $(x_o, y_o, 0)$ when $\bar{\theta}$ and $\bar{\gamma}$ are both zero. The cylinder can then be rotated around this point by $\bar{\theta}$ and $\bar{\gamma}$. A coordinate system (u, v, w) is defined with respect to the cylinder as shown in Fig. 16 such that when $\bar{\theta}$ and $\bar{\gamma}$ are zero, the u-, v- and w-axes, (shown as the x'-, y'- and z'-axes) are parallel to the x-, y- and z-axes respectively. For any rotations of $\bar{\theta}$ and $\bar{\gamma}$ the relationship between the (x, y, z) and (u, v, w) coordinate systems can be expressed by the following transformation equation:

$$\begin{pmatrix} u \\ v \\ w \end{pmatrix} = \begin{pmatrix} \cos\bar{\gamma} & 0 & \sin\bar{\gamma} \\ \sin\bar{\theta}\sin\bar{\gamma} & \cos\bar{\theta} & -\sin\bar{\theta}\cos\bar{\gamma} \\ -\cos\bar{\theta}\sin\bar{\gamma} & \sin\bar{\theta} & \cos\bar{\theta}\cos\bar{\gamma} \end{pmatrix} \times \begin{pmatrix} x - x_o \\ y - y_o \\ z \end{pmatrix} \quad (16)$$

where $\bar{\theta}$ and γ are positive when measured as in Fig. 16.

The equation of the cylinder $u^2 + v^2 = r^2$ is then expressed in terms of x, y, and z as follows:

$$ax^2 + by^2 + cz^2 + 2fyz + 2gxz + 2hxy + 2lx + 2my + 2nz + d = 0 \quad (17)$$

where

$$a = \cos^2\bar{\gamma} + \sin^2\bar{\theta}\sin^2\bar{\gamma}$$
$$b = \cos^2\bar{\theta}$$

[4] Numbers in brackets designate Additional References at end of discussion.

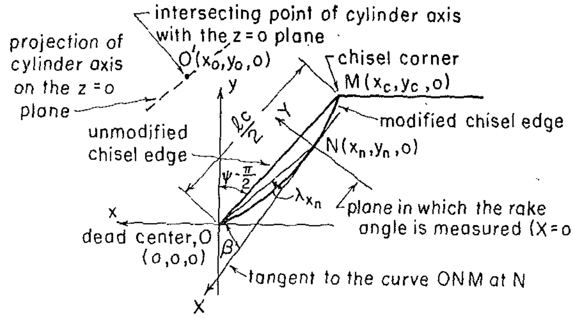

Fig. 17 Configuration of modified chisel edge

$$c = \sin^2\bar{\gamma} + \sin^2\bar{\theta}\cos^2\bar{\gamma}$$
$$f = -\tfrac{1}{2}\sin 2\bar{\theta}\cos\bar{\gamma}$$
$$g = \tfrac{1}{2}\sin 2\bar{\gamma}\cos^2\bar{\theta}$$
$$h = \tfrac{1}{2}\sin 2\bar{\theta}\sin\bar{\gamma}$$
$$l = -(ax_o + hy_o)$$
$$m = -(hx_o + by_o)$$
$$n = -(gx_o + fy_o)$$
$$d = ax_o^2 + by_o^2 + 2hx_oy_o - r^2$$

The modified chisel edge can be obtained by substituting $z = 0$ into equation (17) if the chisel edge is assumed to lie on plane P_o, and is given by

$$ax^2 + by^2 + 2hxy + 2lx + 2my + d = 0 \quad (18)$$

Since the modified chisel edge passes through the dead center 0 and the chisel edge corner M of the unmodified drill point shown in Fig. 17, equation (18) must be satisfied by $(x, y, z) = (0, 0, 0)$ and $(x, y, z) = \left(-\frac{l_c}{2}\sin\left(\psi - \frac{\pi}{2}\right), \frac{l_c}{2}\cos\left(\psi - \frac{\pi}{2}\right), 0\right)$. This yields the values of x_0 and y_0 as roots of the following equations

$$\begin{aligned} d = ax_o^2 + by_o^2 + 2hx_oy_o - r^2 = 0 \\ ax_c^2 + by_c^2 + 2hx_cy_c + 2lx_c + 2my_c + d = 0 \end{aligned} \quad (19)$$

where:

$$x_c = -\frac{l_c}{2}\sin\left(\psi - \frac{\pi}{2}\right)$$
$$y_c = \frac{l_c}{2}\cos\left(\psi - \frac{\pi}{2}\right).$$

The inclination angle λ_n at a point $N(x_n, y_n, 0)$ on the modified chisel edge is now given by:

$$\lambda_{x_n} = \tan^{-1}\left(-\frac{ax_n + hy_n + l}{hx_n + by_n + m}\right) - \tan^{-1}\left(\frac{y_n}{x_n}\right) \quad (20)$$

where (x_n, y_n) must also satisfy equation (18).

The normal rake angle γ_n at point N is measured in a plane normal to the tangent NX to the modified chisel edge at point N. We now move the coordinate system (x, y, z) to the coordinate system (X, Y, Z) by translation and rotation such that the origin O and the x-axis will coincide with point N and the X-axis respectively as shown in Fig. 17. The transformation equation between the coordinate system (x, y, z) and the coordinate system (X, Y, Z) is given by:

$$\begin{pmatrix} X \\ Y \\ Z \end{pmatrix} = \begin{pmatrix} \cos\beta & -\sin\beta & 0 \\ \sin\beta & \cos\beta & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x - x_n \\ y - y_n \\ z \end{pmatrix} \quad (21)$$

where

$$|\beta| = \left|\tan^{-1}\left(-\frac{ax_n + hy_n + l}{hx_n + by_n + m}\right)\right|$$

and β is positive when the rotation is made as shown in Fig. 17. If we express the equation of the cylinder in terms of X, Y and Z by substituting equation (21) into equation (17), and substitute $X = 0$ into the resulting equation, the cross section of the cylinder cut by the $X = 0$ plane is given by

$$b'Y^2 + c'Z^2 + 2f'YZ + 2m'Y + 2n'Z + d' = 0 \quad (22)$$

where

$$b' = a \sin^2 \beta + b \cos^2 \beta + h \sin 2\beta$$

$$c' = c$$

$$f' = f \cos \beta + g \sin \beta$$

$$m' = ax_n \sin \beta + by_n \cos \beta + hx_n \cos \beta + hy_n \sin \beta + l \sin \beta + m \cos \beta$$

$$n' = gx_n + fy_n + n$$

$$d' = ax_n^2 + by_n^2 + 2hx_ny_n + 2lx_n + 2my_n + d$$

We can now obtain the normal rake angle by differentiating equation (22) with respect to Z and evaluating at $Y = 0$ and $Z = 0$ yielding:

$$\tan \gamma_n = -\left.\frac{f'Y + c'Z + n'}{b'Y + f'Z + m'}\right|_{\substack{Y=0\\Z=0}} = -\frac{n'}{m'} \quad (23)$$

Thus, the inclination and the normal rake angles at any point on the modified chisel edge can be obtained by equations (20) and (23) respectively under the assumption that the modified chisel edge lies on a plane perpendicular to the drill axis.

To eliminate this assumption from the analysis, the true configuration of the modified chisel edge must be accurately obtained. For example, if a drill point is ground by the conical grinding method, its flank surface is a portion of a grinding cone surface, and one side of the flank contour is a portion of an ellipse in a plane perpendicular to the drill axis as was shown in reference [7]. Thus, the configuration of the modified chisel edge would be the intersection between the cylinder and the cone, and can be found by connecting the intersecting points of the cylinder and cone cross sections on a series of planes perpendicular to the drill axis.

The inclination angle and the normal rake angle can then be obtained by specifying the planes on which these angles are measured and following the procedure similar to that described above.

While the writers did not go into the orthogonal and effective rake angles in their analysis, it is felt that the equations for these equations (12) and (14) are not satisfactory if they are based upon the three assumptions cited above.

The inclination angle and the normal rake angle can be theoretically analyzed. However, if the analysis are based on the assumption that the modified chisel edge passes through the dead center and a chisel edge corner of the unmodified chisel edge, it may be very difficult to set up the grinding wheel to perform this grinding accurately. It is recommended that the coordinates (x_c, y_c, z_c) of the chisel edge corner of the modified drill be measured and to estimate the position of the cylinder axis (x_o, y_o, z_o) instead of using the theoretical coordinates $\left(-\frac{l_c}{2}\sin\left(\psi - \frac{\pi}{2}\right), \frac{l_c}{2}\cos\left(\psi - \frac{\pi}{2}\right), 0\right)$ given by Eq. 19.

Additional References

6 Galloway, D. F., "Some Experiments on the Influence of Various Factors on Drill Performance," Trans. ASME, Vol. 79, 1957, pp. 191–231.

7 Fujii, S., DeVries, M. F., and Wu, S. M., "An Analysis of Drill Geometry for Optimum Drill Design by Computer, Part I—Drill Geometry Analysis," Journal of Engineering for Industry, Trans. ASME, Series B, Vol. 92, No. 3, Aug. 1970, pp. 647–656.

8 Fujii, S., DeVries, M. F., and Wu, S. M. "An Analysis of Drill Geometry for Optimum Drill Design by Computer, Part II—Computer-Aided Design," Journal of Engineering for Industry, Trans. ASME, Series B, Vol. 92, No. 3, Aug. 1970, pp. 657–666.

9 Fujii, S., DeVries, M. F., and Wu, S. M., "Analysis of the Chisel Edge and the Effect of the d-theta Relationship on Drill Point Geometry," Journal of Engineering for Industry, Trans. ASME, Series B, Vol. 93, No. 4, Nov. 1971, pp. 1093–1105.

Authors' Closure

The authors are glad and feel encouraged having their paper being thoroughly read and discussed by Messrs. S. Fujii and M. F. DeVries, renowned in the field of drilling technology and who have pointed out some interesting and valuable points on said paper.

Based on the discussion aforementioned the authors would like to make the following points:

1 The geometrical analysis made by the authors is based on the assumptions as mentioned by the discussers.

2 The shape of a drill at its point itself is very complex which is further complicated by introducing additional slots at the chisel edge zone at desired inclination and orientation. Hence, it becomes very difficult to analyse the geometry and develop mathematical models for it without taking the aid of some assumptions.

Beside that, further assumptions are needed to make the problem simpler so that the objectives could be easily realized.

It is true that more assumptions make the models more approximate and inaccurate but still the authors have used many assumptions only to avoid complicacy as a first approach, and also to provide a physical conception of the new modified drill.

3 The authors appreciate the discussers' more mathematical approach in analysing the geometry which reduces the inaccuracy of models by minimizing the number of assumptions.

4 The authors agree with the discussers regarding the designation of chisel edge angle, ψ, and it has already been employed by the authors in their subsequent work and papers as shown in Fig. 18.

However many writers are still using the old designation of ψ as has been previously employed by the present authors.

5 The discussers are requested to see whether equation (15) and the subsequent equation given by them in their discussion could be replaced by or rewritten in the form

$$\lambda_x = -\frac{1}{2}\left[\sin^{-1}\left(\frac{r\cos\alpha + \frac{l_c}{2}\sin\psi + x}{r}\right) - \sin^{-1}\left(\frac{r\cos\alpha + \frac{l_c}{2}\sin\psi}{r}\right)\right]$$

where, $\sin \alpha = y/r$
and

$$y^2 - y \cdot \frac{l_c}{2}\cos\psi + \left(\frac{l_c}{4}\right)^2 - r^2 \sin^2 \psi = 0$$

6 The value of "r" of Fig. 15 is recommended to be equal to or slightly bigger than half the web thickness for better performance.

7 The mistake as indicated in Fig. 4 is simply due to a drafting slip because it is quite obvious that at $\frac{r_x}{R} = 0$, $\lambda_x = 0$ which is also evident from the equation presented by the authors.

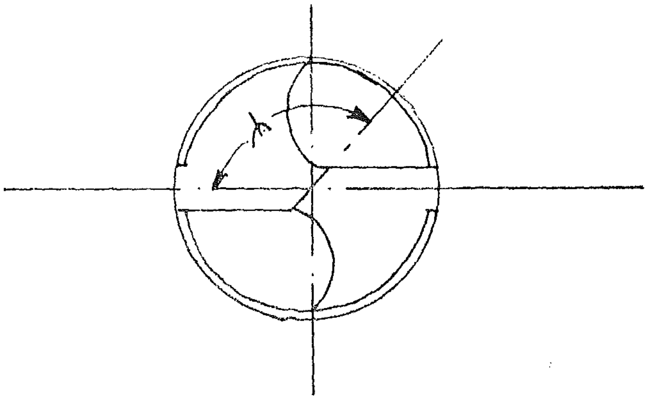

Fig. 18

8 The orientation or inclination angle, $\bar{\theta}$, and setting angle, $\bar{\lambda}$, have been used one for the other by the discussers.

9 The authors have thought that Fig. 16, showing the relationship among the coordinates of drill and those of additional cylindrical slots at the chisel edge, may be slightly modified for better understanding as shown in Fig. 19.

$$\begin{bmatrix} u \\ v \\ w \end{bmatrix} = [T'_{\bar{\gamma}}]\,[T_{\bar{\theta}}] \begin{bmatrix} x - x_0 \\ y - y_0 \\ z \end{bmatrix}$$

where,

$$[T_{\bar{\theta}}] \begin{bmatrix} \cos\bar{\theta} & 0 & \sin\bar{\theta} \\ 0 & 1 & 0 \\ -\sin\bar{\theta} & 0 & \cos\bar{\theta} \end{bmatrix}$$

and

$$[T_{\bar{\gamma}}] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos_{\bar{\gamma}} & -\sin_{\bar{\gamma}} \\ 0 & \sin_{\bar{\gamma}} & \cos_{\bar{\gamma}} \end{bmatrix}$$

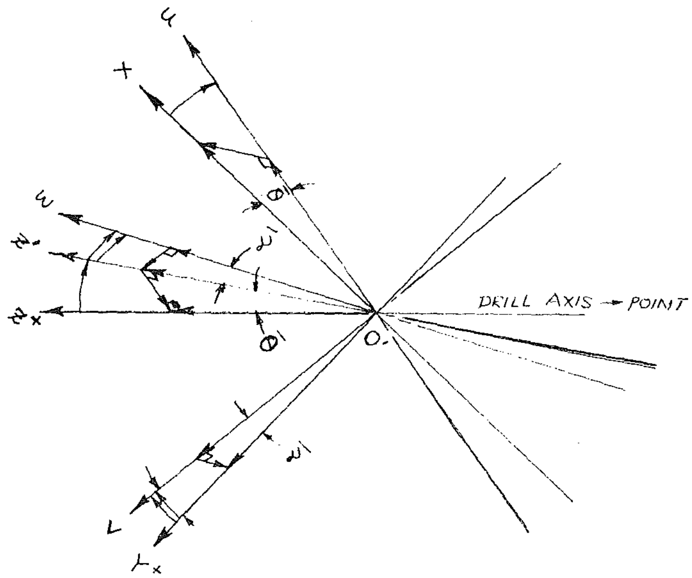

Fig. 19

i.e.,

$$\begin{bmatrix} u \\ v \\ w \end{bmatrix} = \begin{bmatrix} \cos\bar{\theta} & 0 & \sin\bar{\theta} \\ \sin\bar{\theta}\sin\bar{\gamma} & \cos\bar{\gamma} & -\cos\bar{\theta}\sin\bar{\gamma} \\ -\sin\bar{\theta}\cos\bar{\gamma} & \sin\bar{\gamma} & \cos\bar{\theta}\cos\bar{\gamma} \end{bmatrix} \begin{bmatrix} x - x_0 \\ y - y_0 \\ z \end{bmatrix}$$

If the geometrical elements are presented in their full mathematical form they would become so large and complicated that it will be difficult to realize and also to have a physical conception. Consideration of geometrical parameters of complex curved shape of the drill flank at the chisel edge which is also important from a scientific point of view is liable to make the modelling complicated.

Bearing in mind all these facts, the authors feel the utility and necessity of such small and simple equations, at least for the first approach in this field of modified drills, was necessary.