

# THE SCREW-CONVEYOR VANE DESIGN FOR PIECE-WISE CONSTRUCTION

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## Summary

One of the long-used methods of conveying granular, Powdery or slurry material is by the screw conveyor. This method of transport is well suited to some at the needs of local processing Industries based on such local produce as millet, maize, cocoa-beans, rice, palm-kernels. The spiral vanes of such conveyors are manufactured to customers' specifications by a few steel-rolling industries by a continuous conical-rolling technique in which considerable differential deformation of the steel strip is achieved. Such a method of manufacture is beyond the resources of a general-purpose metal workshop that may require the odd spiral vane once in a while and can neither afford the time nor the cost of ordering from abroad. In this article the method of six blanks which the author has developed for the building up of the vane progressively from blanks is presented.

## INTRODUCTION

As illustrated in Fig. 1 the screw-conveyor consists of an encased shaft to which a spiral blade is rigidly attached.

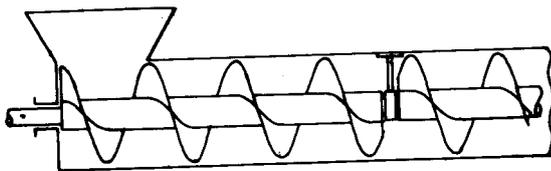


Fig 1

Rotation of the shaft causes the attached blade to push material contained in the trough of the casing from one end to the other. (1) The rate of delivery varies with the speed of the shaft. Because of the positive nature of the propelling action, the axis of the casing can be at an angle to the horizontal, thus enabling material to be raised over a height. Where fine tolerances have been maintained in the manufacture, the spiral blade can withstand axial load. The device can therefore be suitable for feeding material through a constriction such as is encountered in the extrusion action required in liquid-content extraction and in briquetting. However, the appliance finds the most common use in the conveying of an innumerable range of powdery and granular materials (2) such as pulverised coal, cement fertilizers, flour and animal feeds, furnace-ash. It is very well suited to some of the needs of processing industries based on such local produce as millet. Maize, cocoa-beans, rice, palm-kernels. The garri-processing plant developed by the project Development Agency at Enugu in the East Central

State of Nigeria utilised paddles functioning as an interrupted ribbon-flight screw-conveyor.

This article has been prompted by the difficulty attendant to the manufacture of spiral conveyor vanes in general-purpose workshops.

## WHY CHOICE OF METHOD IS RESTRICTED

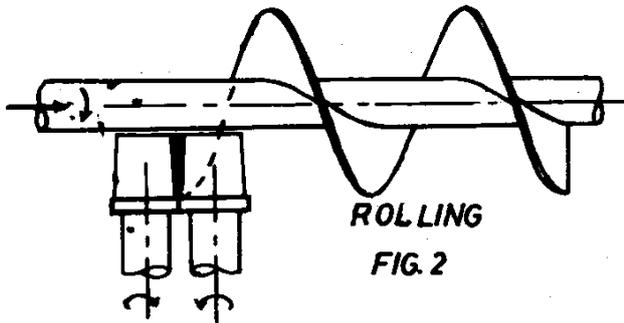
Although there are several manufacturing methods which may suggest themselves, when each of these is examined in the context of a scantily equipped workshop, they are disqualified on one or both of the grounds of feasibility and cost.

Because of the specialised equipment required in conical-rolling or hot-twisting, the principles of which are illustrated in Figs 2 and 3 respectively, these methods are only suitable for steel mills highly capitalised for mass-production.

It is possible to produce the vane-conveyor rotor integrally by machining from stock. However, a satisfactory solution is not achieved by using an ordinary screw-cutting lathe because of the following reasons. If the raw material is a solid circular section, a great amount of metal (up to 96%) would have to be removed by a slow and tedious turning process requiring crafts-man labour. Raw material and labour costs, machine time and tool wear would render the cost of the product prohibitive. Secondly, spiral blades for conveyors unlike screw threads, usually have a large axial pitch. Therefore in manufacturing by machining on a screw-cutting lathe, a low head-stock speed is associated with a high lead-screw speed. This because of the inertia of the moving parts of the transmission and the saddle produces a dangerous condition if a special-purpose lathe designed for this kind of work is not available. Finally, the axial length of rotor which can be machined continuously is limited by the travel of the lathe.

It might appear that production by machining could be made more competitive if this is based on stock that has been prepared by forging. This is not so because a large reduction in the radial dimension of the greater part of the billet is required. Added to the cost of the short-lived and expensive dies required, the method is found to hold no advantage. For completeness, it is necessary to show why methods of sand and die casting including the lost-wax process, do not provide the solution. The first reason is that some of the difficulties that face the manufacture of the conveyor rotor in metal also face the preparation of the pattern in wood. But even where a suitable pattern has been contrived, the relative thinness of the blade section combined with its usually large radial depth introduces pitfalls due

to distortion and cracking of the casting. Even if adequate precautions are taken to ensure preheating of the mould and controlled cooling of the casting, the design of the mould is complicated by the nature of the geometry of the blade surface. The method of casting does not therefore provide a satisfactory solution except in the case of a shallow blade on a short shaft such as is used in domestic grinders.



**THE METHOD OF SIX BLANKS**

One of the methods of construction which has been used by the author and found suitable for the labour-intensive type of general-purpose workshop available in some places in this country, builds up a pitch length of the blade from six identical plane blanks which have been suitably proportioned. The outer edge of each blank may be twisted through a calculated angle relative to the inner edge before the blank is welded to the shaft.

The approach for the design of the blank is based on the fact that when a uniform diameter cylinder is viewed transversely, a limited length of path of any spiral of constant angle drawn on it can be approximated by a straight line. In fact, any length of path of the spiral which has an included angle of 60° or less at cylinder centre (as seen in an axial view) can be approximated by a straight line. In Fig 5 which shows a transverse view of half a pitch length of a uniform spiral blade, the curves a a and b b are parts of the projection of the minor and major spirals and each corresponds to 60° included angle.

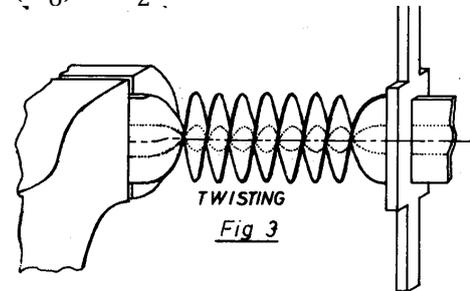
The degree of error arising from our basic assumption of straightness, over 60° angle can easily be checked quantitatively. It can be shown that the projection on a transverse plane of a right-

circular cylindrical spiral of constant angle, fig 4, is the sinuous curve.

$$y = R \sin 2\pi \frac{x}{p} \tag{1}$$

Where y = normal displacement from cylinder axis  
 R = radius of cylinder  
 x = displacement along cylinder axis  
 and p = axial pitch of spiral.

The part AB of the curve in Fig. 4 extends over 1/6th of the pitch and is the curve whose deviation from straightness is of interest. At A and B

$$\frac{y}{R} \times \sin\left(\mp \frac{\pi}{6}\right) = \mp \frac{1}{2}$$


Therefore, a straight line AB, which by symmetry must pass through the origin O, is given by

$$\frac{y}{R} = 6 \frac{x}{P}$$

and the deviation is given by

$$\Delta = R = \sin 2\pi \frac{x}{p} - 6R \frac{x}{p} \tag{2}$$

In our problem where for the straight line AB the maximum value of x/p is π/12 the error arising from taking only the first two terms of the Taylor expansion of the sin-term of eqn 2 is of the order of 0.05 %. Therefore, the deviation may be expressed by

$$\Delta = 2\pi R \frac{x}{p} \left[ 1 - \frac{2\pi^2}{3} \left(\frac{x}{p}\right)^2 \right] - 6R \frac{x}{p}$$

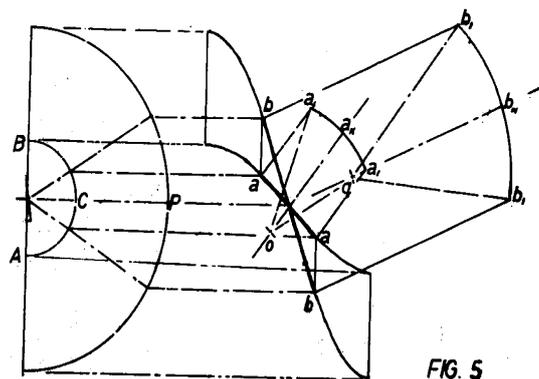
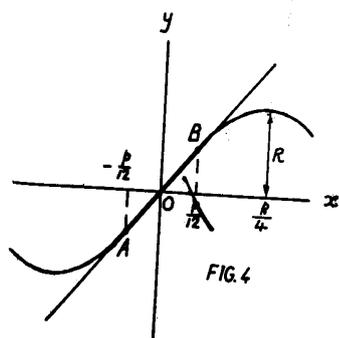
From this, the maximum deviation is found to occur at

$$\frac{x}{p} = \sqrt{\frac{\pi - 3}{2\pi^3}} = 0.0475$$

so that its value is

$$\Delta_{max} = R \sin 2\pi \frac{x}{p} - 6R \frac{x}{p} = 0.009R.$$

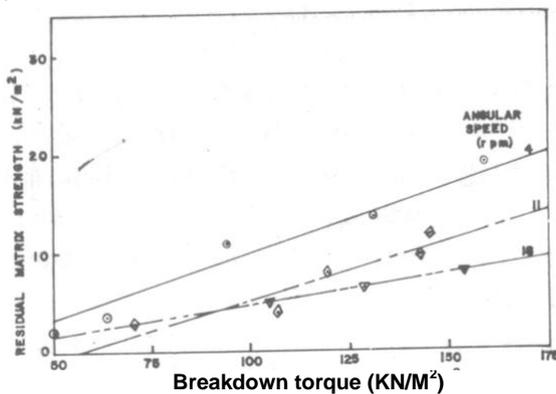
which represents a maximum deviation of 3%. Referring again to fig 5, we proceed to determine



the shape of a flat plate which can be used to approximately from the curved surface a, b, b, a. We first determine the true shapes of the elliptically arcs of aa, and bb, each of which arc, subtends 60° in an axial view and is assumed to sufficiently lie in one plane. These shapes are found by the usual methods of graphics and are shown as a, a, a, and b. b., b. Further work will be based on either curve a, a., a, or on curve b. b., b. depending on whether the spiral blade is male or female.

As this discussion develops, it will be seen that only a chosen one of the curves a, a., a, and b. b., b can be rigorously determined whether, this be achieved by graphics or by computation. The choices of which of the two curves will be rigorously determined will, in practice, depend on whether the blade is male or female. In the case - of an internal vane formed inside a tumbling barrel, for example, the blade is not attached directly to a shaft but is fastened to the inner surface of the barrel. In this case, the curve b. b.,b. must fit the inner surface of the barrel and is the one on which the design of the blank should be based. On the other hand, in an external spiral blade construction such as is shown in Fig 1, the blade is attached to the shaft and may not even touch the casing. The curve a, a.,a, must in this case fit the shaft and is the one on which the design should be based. Since this type is more common, we shall, proceed by using curve a, a.,a, for illustrating the method of design of the blank.

We now assume that a flat plate exists which can form the surface a b b a, by the twisting of its upper edge relative to its lower edge through the acute angle included by the projections aa and bb. If this plate can be identified by the parameters of Fig. 6, it remains to evaluate these parameters for each particular case.



**FIG 6. CORRELATION BETWEEN BREAKDOWN TORQUE AND RESIDUAL MATRIX STRENGTH**

These dimensions can be determined purely by calculation, thus avoiding the need for any graphical work. Let the specifications be as follows:

- d = diameter of shaft
- D = outside diameter of blade
- P = axial pitch of the screw
- d<sub>1</sub> = spiral angle on the shaft
- d<sub>2</sub> = spiral angle on cylinder of diameter D
- ℓ<sub>60</sub> = length of path of 1/6th pitch of minor spiral
- L<sub>60</sub> = length of path of 1/6th pitch of major spiral

Then

$$\begin{aligned} \tan \alpha_1 &= \frac{\pi d}{p} : \ell_{60} = \frac{\pi d}{6 \sin \alpha_1} \\ \tan \alpha_2 &= \frac{\pi D}{p} : L_{60} = \frac{\pi D}{6 \sin \alpha_2} \end{aligned} \tag{3}$$

To determine  $\gamma_\beta$  (Fig.6), referring to Fig.7  $\gamma_\beta$  is the radius of a circular arc with three precision points at a'' a'', and a, of the elliptical section of the shaft with radius of curvature  $\gamma_c$  at the point a'' made by a cutting plane at an angle d to the axis of the shaft. Let B be the angle included at shaft centre by the element of spiral (60°). The circular arc of best fit over the region B has its centre at O radius  $\gamma_\beta$

$$\gamma_\beta^2 o \ell^2 + \frac{1}{4} (o_1 o_1)^2$$

By the construction, it can be ascertained that

$$O \ell = \gamma_\beta - \frac{d}{2} \left( 1 - \cos \frac{\beta}{2} \right) : \text{and } o_1 o_1 = d \cdot \frac{\sin \frac{B}{2}}{\sin \alpha}$$

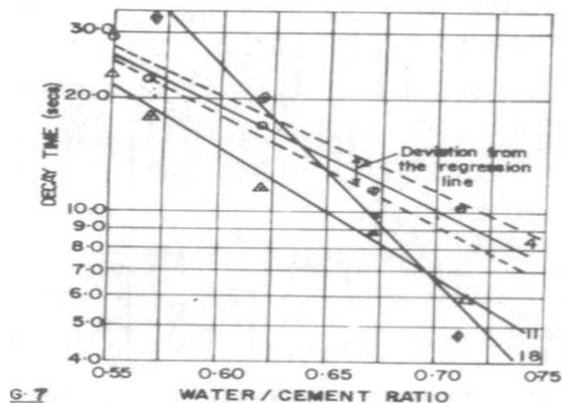
We therefore find that  $\gamma_\beta$  is given by

$$\gamma_\beta = \frac{d}{4} \left[ \left( 1 - \cos \frac{\beta}{2} \right) + \frac{\sin^2 \frac{\beta}{2}}{(1 - \cos \frac{\beta}{2}) \sin^2 d} \right]$$

we may express  $\gamma_\beta$  as

$$\gamma_\beta = r - \frac{1}{2} \left( r_c - \frac{d}{2} \right) \left( 1 - \cos \frac{\beta}{2} \right) \tag{4}$$

Since  $\gamma_c > d/2$ , this equation shows that  $\gamma_c$  is greater than  $\gamma_\beta$  which is otherwise obvious. The difference between  $\gamma_c$  and  $\gamma_\beta$  can be quite significant and it is not recommended that  $\gamma_c$  should be used in place of  $\gamma_\beta$  as fig 7 might seem to suggest.



**Fig. 7: VARIATION OF DECAY TIME WITH WATER/CEMENT RATIO.**

For example, if the minor helix angle is 45° the radius of curvature is d while  $\gamma_\beta$  has the value 0.966d, a difference of about 4%.

To calculate  $\gamma$  since arc a,a equals 1/6th travel of the minor spiral, we must have

$$\gamma_1 = \frac{\ell_{60}}{\gamma_\beta} = \frac{\pi d}{6 \gamma_\beta \sin d_1} \tag{5}$$

To calculate  $R_o$ . we may assume that arc b, b, must be concentric with a, a., and therefore get

$$R_o = \gamma_\beta + \frac{D-d}{2} \tag{6}$$

Then since the arc length b, b, is assumed to be preserved after twisting the plate and is 1/6th path length of one pitch of the major spiral, angle will be given by

$$r_2 = \frac{L_{60}}{R_o} = \frac{\pi D}{6 \left( \gamma_\beta + \frac{D-d}{2} \right) \sin d_2} \tag{7}$$

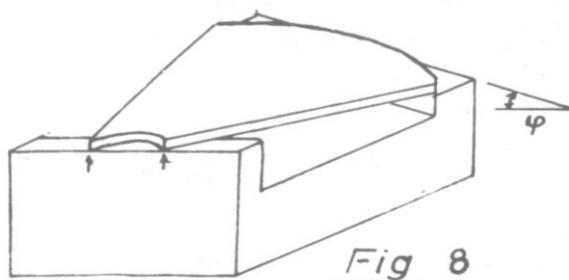
The plane blank is now completely determined. Within the limits of our basic assumptions, has been correctly determined by calculation based on the elliptical section of shaft. The form of the outer arc  $b$ ,  $b$ , has, however, been arbitrarily fixed on the assumption that subsequent twisting will not cause significant changes in the length of path from one point to the other on the plate surface. The only justification for this assumption is that it has, in practice, given good results.

The procedure is successful for the case of a male spiral blade attached to a shaft. But if the method is to be applied in the case of an internal fin,  $R_o$  must be calculated by appeal to the corresponding elliptical section. Then  $r_\beta$  is found by making  $(R_o - r_\beta)$  equal to the radial depth of the blade.

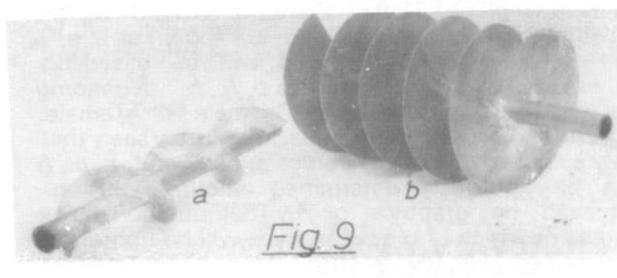
Fig. 5 suggests that we can now prepare the blank for welding onto the shaft by twisting the outer edge relative to the inner edge while keeping both edges straight. In doing this, either of two procedures may be followed.

In the first procedure, the twisting of the blank is done before the blank is welded to the shaft. Good results are obtained if the blade has a short radial depth. The inner edge is gripped in a vice and a suitable wrench, which is easily fabricated for the purpose, is used for the twisting. It is useful to employ a gauge designed to show when the correct relative twisting has been reached. This can be made from a block of hard wood, as illustrated in Fig. 8. In this gauge, the angle between the horizontal and inclined surfaces on which the ends of the blank rest is equal to the desired angle of twist, that is

$$\varphi = \tan^{-1} \frac{\pi D}{p} - \tan^{-1} \frac{\pi d}{p}$$



At some stage of the twisting of the blank, it will be found necessary to straighten the radial edges which tend to bend due to the grip of the vice. Fig 9 (a) Shows a rotor fabricated this way. The plate was 4 mm thick, the shaft was 3.2 cm diameter, the axial pitch was 15 cm and the radial depth of the vane was 35cm.



second procedure. The first procedure does not succeed in the case of a blade with a large radial depth (about 5 cm for a plate thickness of 3.2 mm). If the blank is twisted and hammered cold, the two radial edges cannot both be restored to straightness. A successful assembly can however, be achieved in the following manner. The blanks are successively welded to the shaft without prior twisting. After being rigidly joined to the shaft, the vane is easily hammered into alignment with its preceding neighbour (which is also tapped) before being welded to it. By this method, buckling of the blade can be avoided. In many cases, a relieve of the fabrication stresses arising from this process is not necessary. A rotor fabricated in this way [3] is shown in Fig. 9 (b) The plate was 4 mm thick, the shaft was 3.2 cm diameter, the axial pitch was 7.5 cm and the radial depth of the vane was 10 cm.

Whichever method of assembly is used to facilitate the accurate location of the blanks on the shaft, it is necessary to trace the path of the minor spiral on the shaft so as to indicate graphically where the blanks should be placed. A suitable centre- lathe, if available serves this purpose best; otherwise the trace can equally well be produced by wrapping the well-known right-angled triangle of base  $\pi d$  and height  $p$ .

**REFERENCES**

- (1) T. Baumeister (editor) Mechanical Engineers Handbook
- (2) Link-Belt Company, NY, Screw Conveyors and Screw Feeders.
- (3) Preparation and fabrication work were carried out by the personnel of the Mechanical Engineering Department workshop, University of Nigeria.