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Cold Pilger Tooling Design Key Steps

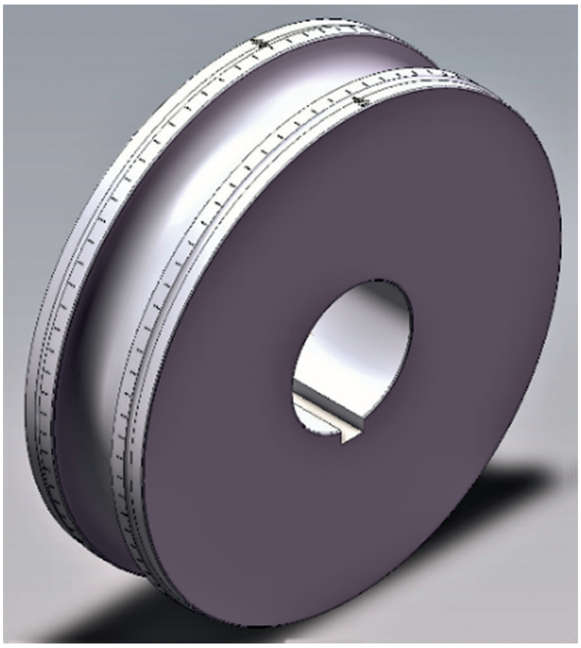

Fig. 1 CAD View

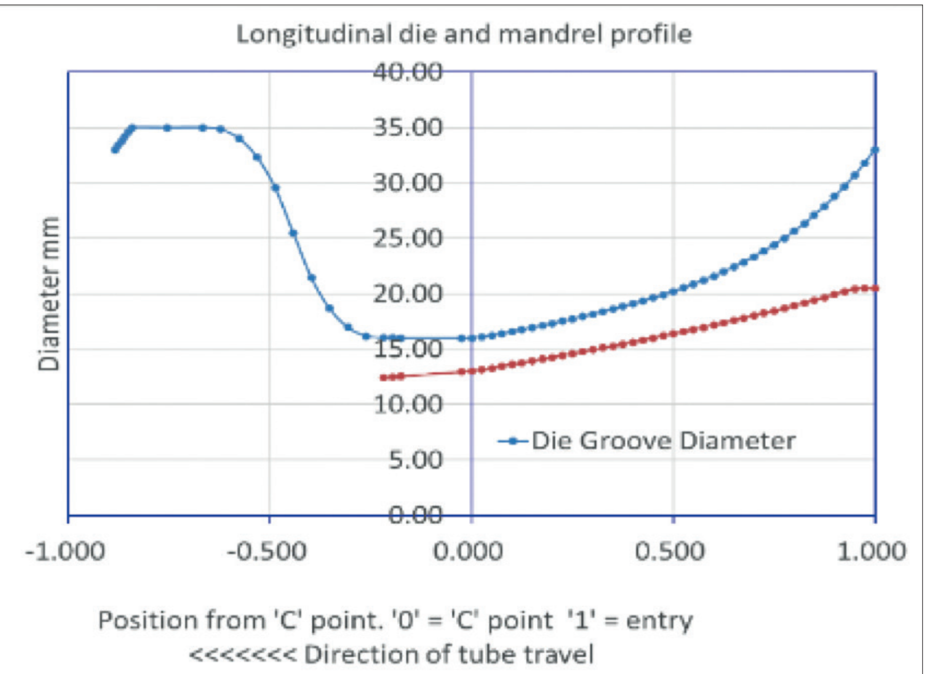

Fig. 2 Longitudinal Profile

The principle

Those familiar with pilger tooling will know that generally there are two ring or half ring dies positioned above each other in a housing so that they can be moved backward and forward over the tube. This imparts a roll profile on the outside of the tube in a progressive manner. Each time the rolls go backward and forward the tube is fed into the roll pinch incrementally. Tube emerges with a smaller diameter and a thinner wall.

There is an equal and opposite profile ground into the circumference of each die and usually there is a mandrel inside the tube with a profile that controls the tube ID and wall thickness.

The fundamental issue is to decide the longitudinal and transverse profile in what has to be a tapered groove in the roll. A coordinated mandrel longitudinal profile is also critical to success as both roll and mandrel together control the strain path.

So, the CAD drawing in Fig 1. shows a typical profile in a single ring die and the Graph in Fig 2. shows a plot in blue of the whole longitudinal die profile measured between the bottom of both opposed grooves through the machine centre line. The red line represents the mandrel diameter. A critical point between these rolls is at the 'C' point. This is nominally where the tooling dimensions will produce the desired tube size. The 'C'point is at position '0.000' on the horizontal axis on Fig 2.

As well as the longitudinal profile there is an equally important transverse profile which is nominally the radius of the tube but also has key elements of 'side relief' which is needed to allow the extending tube to fit into the groove as it progresses forward. It is also needed to accommodate the roll separation under load which produces a larger diameter than initially calculated. A critical measurement which can not easily be calculated is the amount by which the rolls spring together on the forward stroke after they have passed the ‘C’ point. On the return stroke they will spring out by a similar, but not identical amount.

Optimisation

The formular for the early development of these profiles was developed in Europe largely by Mannesmann-Meer and use of the formular proposed in 1969 will still produce results. However, the use of computers – especially powerful lap tops has led to remarkable productivity gains for those prepared to push the boundaries and fully understand the process detail.

The principal working length of the die is normally split into forty segments from the start to the ‘c’ point. There are three principal parameters that need to be calculated for each segment. These are the ‘Q’ factor (which is a measure of the wall strain relative to the diameter strain); The percent reduction (or the total strain if you prefer): and the strain disparity (This is the difference in the strain between the outside tube circumference and the inside circumference). **Together these define the strain path.**

Controlling these parameters in an intelligent way can result in much larger reductions, freedom from lap type inside diameter cold pilger defects and improved dimensional control. Metals with certain crystal atomic configurations can have key mechanical properties controlled. The larger reductions can lead to very large extension of the tube hollows which has significant productivity benefits especially where machines do not have automatic continuous loading. So, Fig 3. shows how these parameters might change as strain path progresses. The horizontal axis is the same as for the previous chart but stops at the ‘C’ point. Note that when the ‘Q’ factor goes below 1 and the strain disparity goes negative there is an increased risk of bore defects.

Roll force determination and side relieve implications

Readers who are following this article will be aware of the importance of side relief issues. Usually, operators use both radial side relief and tangential side relief or sometimes parabolic side relief. Calculating the side relief needed to accommodate the forward movement of the reducing tube can be found in the literature but there is not a lot of practical information available which explains how much of the calculation to use either as part of radial side relief or tangential side relief. Sometimes it can be beneficial to change the amount of tangential relative to radial side relief through the work length.

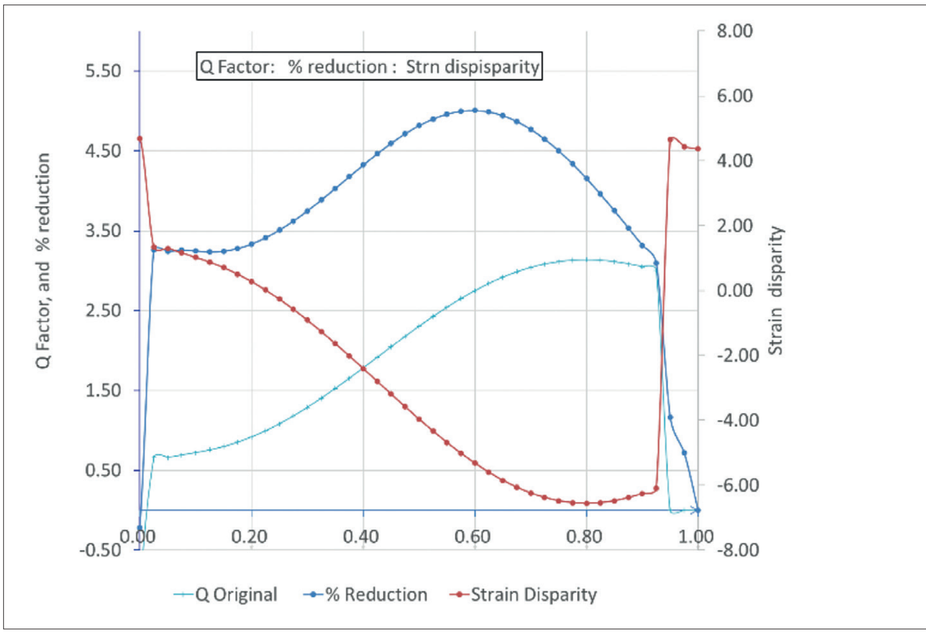

Fig. 3 Key Strain Path Parameters

Calculating the roll force is also possible given the same base calculation as for the above charts but the formula is complicated. The amount of strain hardening has to integrated into these values. The force can be calculated as far as the ‘C’ point on the forward stroke but needs load cell measurement to verify its accuracy and also dimensional measurement to verify the resulting roll separation for use in additional side relief calculation. The Roll separation occurring from the ‘C’ point and the end of the sizing section also needs to be measured.

If operators can perfect the dimensional measurement procedure, they can in theory avoid the use of load measurements but it is easy to see why it would be useful to have both. For instance, for calculating the force on the mandrel and hence how close it might be to breaking. Surprisingly, higher elongations do not necessarily lead to higher loads.

Fundamentally the dimensional measurements are not very difficult but they will be found quite challenging due to the environment in which the measurements have to be taken.

Note that it should be obvious by now that if the machine feed increment is changed after the tooling is manufactured then the entire calculation will not then be correct (assuming it was in the first place). Operators who have not meet the computational

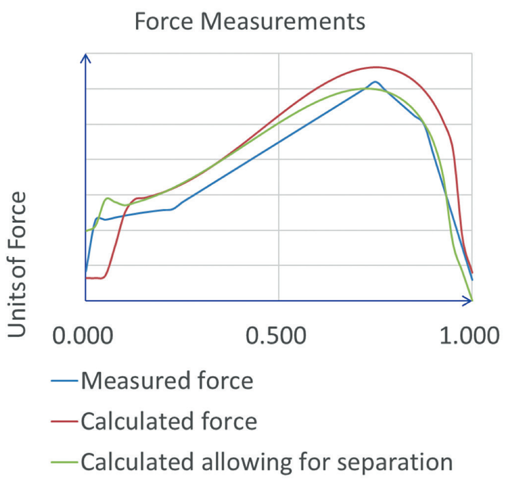

Fig. 4 Roll separation force measurements

Fig. 5 Checking key tooling dimensions

challenges will from time to time find adjusting the feed can produce improvements. Even the most proficient operators may find it necessary to make changes for issues like die wear mid-way through the life of the die. Note that it is it is easy to blame die wear when the problem can be elsewhere – roll bearings for instance.

More Sophistication

Fig 4. shows a plot of calculated and actual values of load separating forces. The green line is a correction for reduction in force as a result of the roll separation. A similar graph can be produced for roll separation values. The horizontal axis is the same as the previous graph.

Getting an operation up to a standard where technicians can produce these graphs with the confidence that they are correct involves hard work - however the benefits can be huge.

There is also a possibility to manipulating the die and mandrel longitudinal profile on the approach to the 'C' point in order to reduce and smooth out the reduction in this area. The wall thickness reduction can be modified to accomplish this and also to modify crystallographic orientation – especially in the radial through wall direction. This is not for the faint hearted and is quite a specialist area.

The Next Step

Up to this point all calculations have been achieved within an excel spreadsheet. There are documents that describe how the spreadsheet works and engineering drawings which define the key dimensions – see Fig 6. These are useful for the tooling manufacturers and the spreadsheet users.

The next step is to convert the spreadsheet to a file capable of downloading to CAD software and finally into the toolmaking machine.

This process also acts as a check that all the die segments are in the correct place and that they match up where they should with the mandrel segments. An especially important check with ring dies is that the mandrel large end and tube hollow

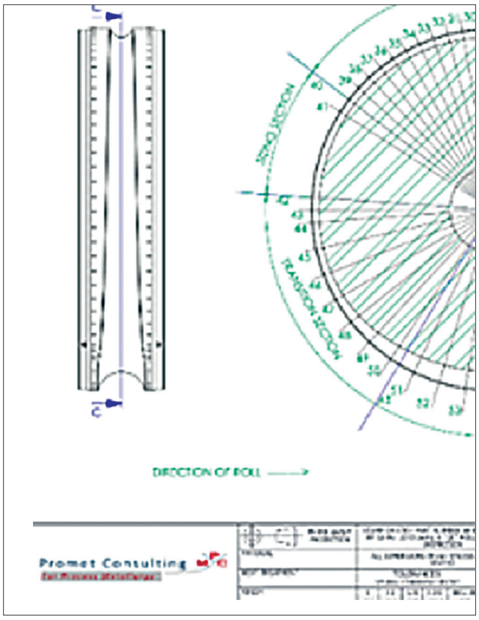

Fig. 6 Purpose designed drawings to match Spreadsheet and CAD files

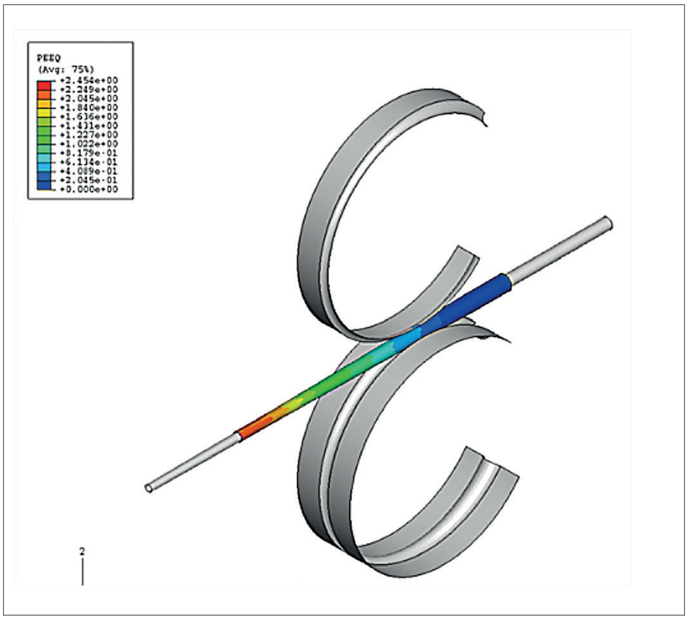

Fig. 7 Typical non-linear FEA analysis of Pilger tooling

together clear the die profile by the specified amount when the dies are in the ET position at the entry end. This is quite tricky to calculate with certainty. In Fig 5. the clearance shows up as a white circle in the centre of the left CAD drawing.

And Finally

Many readers will be aware that Finite Element Analysis can play an important role in processes involving metal deformation. Promet Consulting Ltd had a plan pre COVID to make this a reality but unfortunately it has been delayed.

More accurate predictions of forces, heat 'build up', peak pressure points would certainly be advantageous but all the issues dealt with in this report would be needed to produce viable reductions to try and to provide accurate measurements of forces and roll separations to validate results.

None Linear FEA then can be brought to bear on cold pilgering but issues with very large mesh sizes have limited its use due to cost and time constraints. However, the project was planned to use AI to learn the effects of key variables. As the artificial intelligence developed its predictions would become increasingly reliable and the computational time used in problem solving would be minimal. The system described in this article can be used to rapidly develop and change parameters to input into the FEA Model.

Commercial Note

Promet Consulting Ltd has now been developing the files needed for designing high performance Pilger dies for many years. These files have developed over time which has enabled customers to have the files at very reasonable rates while they have been developed. This initial development is nearing the end and a suit of files is essentially complete but continual development is unlikely to end any time soon. In helping customers to optimise their reductions Promet Consulting Ltd has inevitably acquired some of its customers intellectual property. There may be some potential customers that the company will have to decline to work with due to conflicts of interest but this will depend on many factors. Sometimes materials and reductions can be the same but markets radically different for example.

A group of companies where competition is negligible or very little is ideal for driving forward development and spreading the cost of key projects.

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