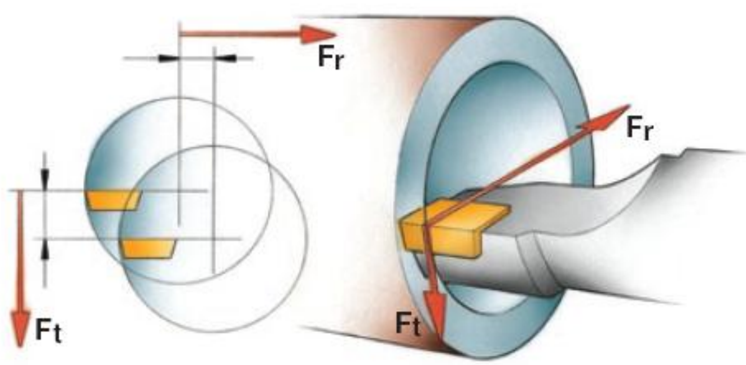
Tips and Ideas – To achieve good accuracies in finish boring with long boring bars.

Most Boring operations take place today on machining centers.
So we are looking at ways and means to get good accuracies in Finish Boring when the Application calls for long Boring Bars (L/D>3.5D) because of reach or deeper bores.

When using long and slender boring bars, the tool deflection is often much larger than the specified dimensional tolerance of the part being machined. When using a boring bar with a diameter of 25 mm and a length of 150 mm the deflection in the finishing cuts is typically 0.05–0.1mm. The magnitude of the deflection is a function of the cutting force.

Let us see the cutting forces that act in a boring operation:



Tangential: forcing the tool down away from the center line and reducing the clearance angle
Radial: Cutting depth and chip thickness is altered, dimension out of tolerance and risk for vibration
These forces vary as per the depth of cut for the same cutting parameters. Now in Finish Boring the depth of cut is much lower so the forces are much lower. Boring Bars in such applications have better static or dynamic stiffness and hence the tangential force Ft gets neutralised but the radial

force Fr causes the Boring Bar deflection; due to this the programmed depth of cut does not get reflected on the finish bore size.

For a given boring operation, the boring bar deflection is to some degree predictable, and the predicted deflection can be corrected for by adjusting the programmed position of the tool tip.

Variations in the tool condition or in the work piece properties will give random variations of the cutting forces. To achieve high dimensional accuracy of each produced part, the parts must be measured during the machining process, and individual corrections must be made in the finishing passes. For example, if the second last pass in the machining operations produces a diameter that is 0.05 mm smaller than expected, the programmed diameter of the last pass must be increased by the same value.

The possibility of achieving high dimensional accuracy of a machined part is higher if the need for correction in the last pass is small. A larger correction will often give less accurate result, and this must be taken into account when the process is designed. The method described here can be used to develop a sequence of passes that will give high accuracy in turning operations with long boring bars.

The **basic three-pass operation** should be used when a new Boring operation is being performed. The basic three-pass operation can be considered as a learning operation to understand the extent of the deflection.

An **improved three-pass operation** is developed from the results achieved in the basic three-pass operation. The known deflection of the boring bar is taken into account when calculating the new optimized depth-of-cut values for the operation.

Basic three-pass operation

Step 1.1: Define the desired finished internal diameter of the product (D_f).

Step 1.2: Measure the diameter before the first pass. (D_{0m})

Step 1.3: Run the first pass. The programmed depth-of-cut should be one third of the machining allowance. The programmed diameter is $D_1 = D_{0m} + (D_f - D_{0m})/3$.

Step 1.4: Measure the diameter after the first pass (D_{1m})

Setp 1.5: Run the second pass. The programmed diameter of the second pass is $D_2 = D_1 + (D_f - D_{1m})/2$.

Step 1.6: Measure the diameter after the second pass (D_{2m})

Step 1.7: Run the third pass. The programmed diameter of the third pass is $D_3 = D_f + D_2 - D_{2m}$

Step 1.8: Measure the diameter after the third pass (D_{3m}) and compare to D_f.

The programmed depth-of-cut of the first pass is 1/3 of the material to be removed. However, because of the deflection of the boring bar, the actual depth-of-cut is much smaller. The boring bar deflection will converge toward a constant value in the second and third pass.

Note that the actual depth-of-cut is relatively large in the second and the third pass.

Example of a basic three-pass operation

Desired finished diameter, D_f = 53.000					
	Programmed diameter	Measured diameter	Programmed d.o.c.	Boring bar deflection	Actual d.o.c.
		D_{0m} = 49.750			
First pass	$D_1 = D_{0m} + (D_f - D_{0m})/3$ $= 50.833$	D_{1m} = 50.340	$\frac{D_1 - D_{0m}}{2} = 0.542$	$\frac{D_1 - D_{1m}}{2} = 0.247$	$\frac{D_{1m} - D_{0m}}{2} = 0.295$
Second pass	$D_2 = D_1 + (D_f - D_{1m})/2$ $= 52.163$	D_{2m} = 51.600	$\frac{D_2 - D_{1m}}{2} = 0.912$	$\frac{D_2 - D_{2m}}{2} = 0.282$	$\frac{D_{2m} - D_{1m}}{2} = 0.630$
Third pass	$D_3 = D_f + D_2 - D_{2m}$ $= 53.563$	D_{3m} = 52.985	$\frac{D_3 - D_{2m}}{2} = 0.982$	$\frac{D_3 - D_{3m}}{2} = 0.289$	$\frac{D_{3m} - D_{2m}}{2} = 0.692$

The programmed depth-of-cut of the first pass is 1/3 of the material to be removed. However, because of the deflection of the boring bar, the actual depth-of-cut is much smaller. **The boring bar deflection will converge toward a constant value in the second and third pass.**

Note that the actual depth-of-cut is relatively large in the second and the third pass.

Improved three-pass operation

In the improved three-pass operation the actual depth-of-cut is of the same size in all three passes.

From diameter measurements in the basic three-pass operation we can find the deflection of the boring bar as a function of the depth-of-cut for the particular combination of insert type and work piece material. This information can be used to achieve a desired actual depth-of-cut.

It is useful to show the deflection as the relation between the programmed d.o.c. and the actual d.o.c. A graphical presentation of this relation from the basic three-pass method in the example above is shown in Figure 2.

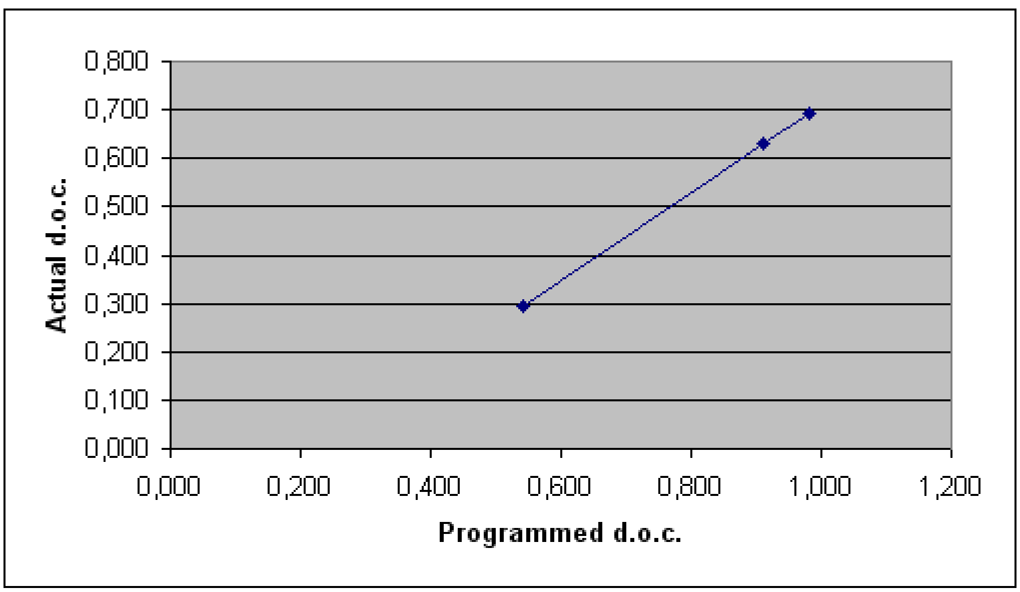


Figure 2. The relation between the programmed d.o.c. and the actual d.o.c. From the graph we see that if an actual d.o.c. of 0.6 mm is desired, the programmed d.o.c. should be approximately 0.88 mm.

The improved cutting operation consists of the following steps:

Step 2.1: Define the desired finished diameter of the product (D_f).

Step 2.2: Measure the diameter before the first pass (D_{0m}).

Step 2.3: Run the first pass. The actual d.o.c. should be one third of the machining allowance. By using the results from the basic operation we find the programmed d.o.c. that corresponds to the desired actual d.o.c. The programmed diameter of the first pass is $D_1 = D_{0m} + 2 \cdot a_{p,prog}$

Step 2.4: Run the second pass. The actual d.o.c. and the programmed d.o.c. should be the same as in the first pass. The programmed diameter of the second pass is $D_2 = D_1 + 2 \cdot a_{p,act}$

Setp 2.5: Measure the diameter after the second pass (D_{2m})

Step 2.6: Run the third pass. The programmed diameter of the third finishing cut is $D_3 = D_f + D_2 - D_{2m}$

Step 2.7: Measure the diameter after the third finishing cut (D_{3m}) and compare to D_f.

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Example of the improved three-pass operation:

Desired finished diameter, D_f = 53.000					
	Programmed diameter	Measured diameter	Programmed d.o.c.	Boring bar deflection	Actual d.o.c.
		D_{0m} = 50,010			
					Acual d.o.c. that should be used in the three passes: $a_{p,act} = \frac{(D_f - D_{0m})/2}{3} = 0.498$
			Programmed d.o.c. that will result in actual d.o.c. of 0.498, from Fig. 2: $a_{p,prog}$ = 0.767		
irst pass	$D_1 = D_{0m} + 2 \cdot a_{p,prog} = 51.543$	D_{1m} (not measured)	$\frac{D_1 - D_{0m}}{2} = 0.767$ (theoretically)	$\frac{D_1 - D_{1m}}{2} = 0.268$ (theoretic ally)	$\frac{D_{1m} - D_{0m}}{2} = 0.498$ (theoretically)
Seco nd pass	$D_2 = D_1 + 2 \cdot a_{p,act} = 52.540$	D_{2m} = 51.970	$\frac{D_2 - D_{1m}}{2} = 0.767$ (theoretically)	$\frac{D_2 - D_{2m}}{2} = 0.285$	$\frac{D_{2m} - D_{1m}}{2} = 0.498$ (theoretically)
Thir d pass	$D_3 = D_f + D_2 - D_{2m} = 53.570$	D_{3m} = 52.995	$\frac{D_3 - D_{2m}}{2} = 0.800$	$\frac{D_3 - D_{3m}}{2} = 0.287$	$\frac{D_{3m} - D_{2m}}{2} = 0.512$

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In both the basic and the improved operation, the second pass is a measuring cut that is used for making an offset before the third finishing pass. The tool should not be indexed between the second and the third pass.

Improved three-pass operation

In the improved three-pass operation the actual depth-of-cut is of the same size in all three passes.

From diameter measurements in the Basic three-pass operation we understand the amount of deflection of the boring bar as a function of the depth-of-cut for the particular combination of insert type and work piece material. This information can be used to achieve a desired actual depth-of-cut

Results from the improved method					
	Programmed diameter	Measured diameter	Programmed ap	Deflection (radial)	Actual ap
Diameter before		50,010			
First pass	51,543	50,990	0,767	0,277	0,490
Second pass	52,540	51,970	0,775	0,285	0,490
Third pass	53,570	52,995	0,800	0,287	0,512

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