Use of trigonometry in calculating the
Maximum orientation error in the manufacturing process

For my Year in Industry, I have been working as a Process Engineer as part of the Mechanical Excellence Team at PEI Genesis UK LTD. PEI Genesis are one of the world's largest electrical connector assemblers and manufacturers. There were numerous occasions when basic maths was involved in solving some of the numerous challenges faced during my placement. One of them, I have detailed below.

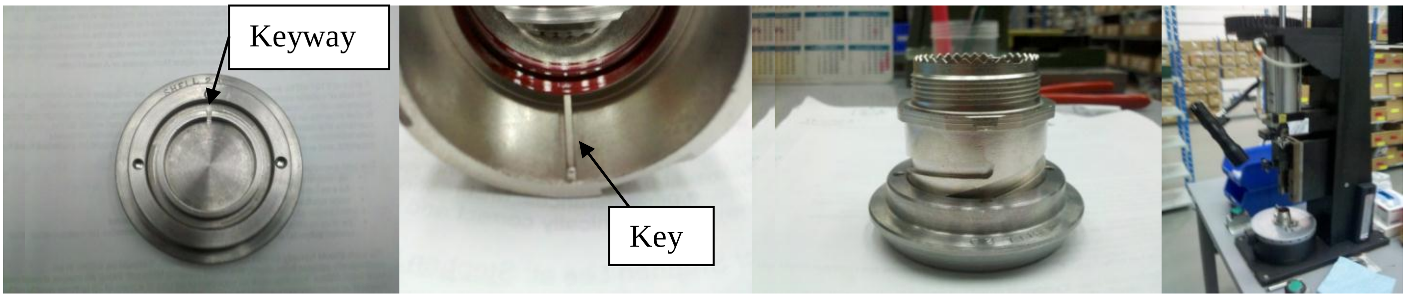
Description of the problem:

In the electrical connector industry, one process in the manufacture of an electrical connector is the insertion of a rubber insulator into a barrel or shell connector usually made out of an alloy.

A tool is needed to hold the connector in the right place whilst a pneumatically activated machine places the insulator inside of the connector. The orientation of this insulator is crucial from a quality perspective i.e. the insulator must be within a certain angular tolerance with the connector.

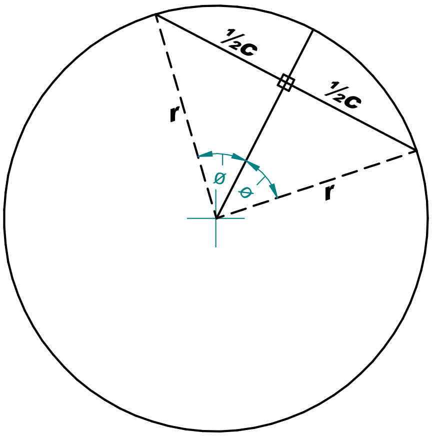
Currently the connector is located on the tool using a keyed joint. A key is a machine element used to connect two rotating machine elements together so as to prevent relative rotation between the two parts. For a key to function the other part must have a keyway, also known as a keyseat, which is a slot or pocket for the key to fit in. The whole system is called a keyed joint. A keyed joint still allows relative axial movement between the parts. As these connectors are manufactured using a moulding process, the keyway sizes on each connector defer slightly. Therefore, when designing the tool, the tool keyway is usually made a tiny bit oversized so as to accommodate all connectors with a range of key sizes.

This however gives rise to a problem. As the keyway is now slightly oversized, the connectors are likely to move radially thus resulting in an orientation error. The manufacture specification allows the orientation error to be within a certain tolerance range, so I was assigned the task to come up with a way to measure the orientation error caused by the oversized keyway for each tool.



Solution:

Developing a formula to calculate the maximum orientation error:



C = Chord length (mm)
r = Radius (mm)
Ø = Angle (radians)
d = diameter (mm)

Using basic trigonometric functions:

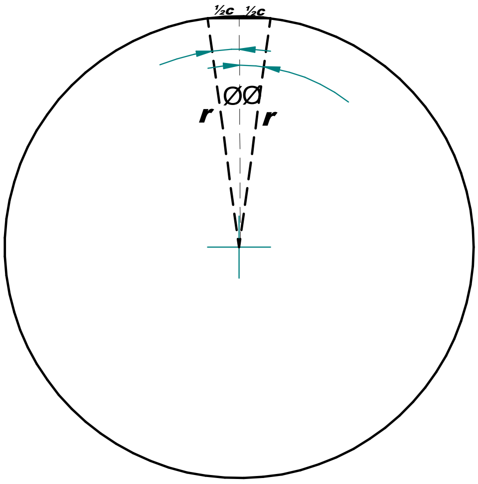
$$\sin\theta = \frac{opposite}{hypotenuse} = \frac{\frac{1}{2}c}{r} = \frac{c}{2r}$$

Therefore:

$$Diameter = 2r = d$$

$$\emptyset = \sin^{-1}\frac{c}{2r} = \sin^{-1}\frac{c}{d}$$

Applying the formula to calculate the maximum orientation error:



C = Chord length (mm)
r = Radius (mm)
Ø = Angle (radians)
d = Diameter

The chord length is the distance that the connector is going to move radially. It is the difference in size of the part keyway and the tool keyway.

To compare the findings to the tolerances in the specification, I needed to convert the answer from radians to degrees using the formula below:

$$degrees = radians \times \frac{180}{\pi}$$

If we take a hypothetical situation where the tool keyway is 1.6mm and the part keyway is 1.5mm, which is a chord length of 0.1mm. The diameter we use here will be the outer diameter of the bore of tool, where the connector will sit in.

So:

C = Chord length (mm) = 0.1mm
d = diameter (mm) = 17.36mm
Ø = Angle (radians) =?

Substitute the date into the equation and you get:

$$\emptyset = \sin^{-1}\frac{c}{d} = \sin^{-1}\frac{0.1}{17.36} = 0.00576\ rad$$

$$\emptyset = 0.00576 \times \frac{180}{\pi} = 0.33^{\circ}$$

So we have calculated that in this hypothetical situation, that the tool will enable us to build a connector with an orientation error between +/- 0.33º.

From this I created a spread sheet in MS Excel with the following formula:

= (ASIN((B1-D1)/(G1-I1)))*(180/PI())

B1= Base Keyway (mm)
D1 = Part Keyway (mm)
G1 = Shell Internal Diameter (mm)
I1 = Base Outer Diameter/Shell Internal Diameter Tolerance (mm)