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Torque testing splined work holders for EV components

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Abstract

As the automotive industry transitions from internal combustion engines (ICE) to electrically powered vehicles (EVs), the tooling required to manufacture EV components must also evolve. In this work, the industry partner is developing new splined collets to be used as work holders in grinding operations for EV splined rotors.

To evaluate the key characteristics of these splined collets, particularly their peak holding torque, a purpose-built torque testing rig was developed. This rig can generate torque levels exceeding 300 Nm, allowing for comprehensive testing under demanding conditions. The collets under evaluation are required to achieve a maximum holding torque of 215 Nm.

It was observed during testing that the collets could repeatedly withstand induced torques exceeding 300 Nm, both clockwise and counterclockwise, without exhibiting any signs of plastic deformation or tooth skipping. These results indicate that the newly developed collets meet and exceed the performance requirements for use in high-torque grinding operations.

Torque Testing, EV, Work holding

1. Introduction

Given the market trend in the automotive sector being more focused on the development and manufacture of electric vehicles (EV), OEMs in the supply chain are having to adapt their traditional manufacturing techniques to incorporate new EV products.

This work focuses on such an adaptation. The work driver shown in **Figure 1** is a standard product manufactured by Craftsman Tools Ltd and is fitted onto a multitude of grinding/turning CNC machines, primarily in the automotive sector. These chucks are typically used in the manufacturing of combustion engine crank/cam shafts.

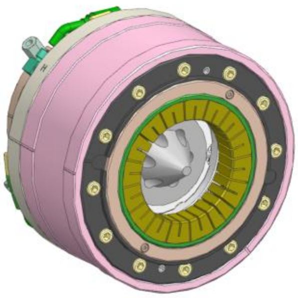

Figure 1: Craftsman Tools Work Driver

The typical operation consists of the smooth crank/cam shaft being clamped into the work holder, by a spring-loaded faceted collet (the yellow ring in Figure 1).

To facilitate new EV products this traditional work driver is being repurposed to accept new splined (as opposed to smooth) shafts, and gears commonly found in EVs, and other growth industries.

This work, with respect to this products transition, is aimed at evaluating the effectiveness of this new splined collect with regards to its work holding properties.

Under manufacturing conditions, the work driver must be able to hold the workpiece rigidly even when subjected to a potential 215 Nm of rotational torque. Under these conditions if the work holder is not able to maintain its clamping effectiveness the work piece could potentially slip, which could lead to at best rework or scrappage, and at worst the work piece being ejected from the machine.

This work is based around the determination that this work driver, can hold the work piece constantly even when subjected to 215 Nm of torque. Therefore, to facilitate this, this work will focus on the design and development of test rig that can apply this torque limit to the work driver whilst monitoring for any unwanted rotation when the work piece is under nominal clamping conditions.

2. Rig design and development

To facilitate the application of torque to the work driver the following test rig was designed shown in **Figure 2**.

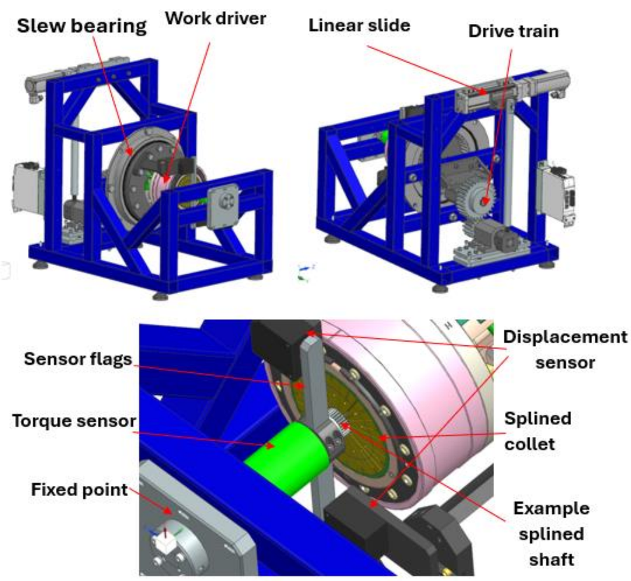

Figure 2: CAD model of the torque test rig

The basic operation of the torque test rig is as follow:

• The work driver via the example splined shaft is attached to an Applied Measurements DTD-S-250Nm torque sensor that is fixed at the fixed point (see **Figure 2**). This is designed to restrict all rotational movement, and ensure any external force applied will be detected by the torque sensor.

• To induce torque on the work driver, on the rear of the rig is a linear slide that is connected to a 6.2:1 gear reduction that also incorporates a geared slew bearing that the work driver is mounted to. The combination of the linear slide and the geared drive train will ensure that a total of 229 Nm is applied to slew bearing and thus the captive work driver.

• Finally, there is a differential pair of Riftek laser triangulation sensors that will monitor the rotational movement of the work drive as the torque is applied. These will also monitor for any slippage that may occur when torque is applied.

As stated, the rig needs to be able to generate at least 215 Nm of torque to determine the holding capability of the work driver. As a single motor capable of generating such torque levels would be extremely costly, a gearing system was derived that can gear up the input torque to the desired levels. The initial force is generated by a linear slide connected to a lever, that is in turn connected to the input of the drive train. This is defined as τ_{in}.
τ_{in} is given by:

$$\tau_{in} = F * D * \sin(\alpha)$$

Where:

Input force F (N)	115
Lever length D (m)	0.5
Force Vector α (rads)	0.7853

This gives an input torque of 40.7 Nm.
To achieve the desired output torque (τ_B) of 215 Nm the input torque is send through a two-stage gear reduction, given by:

$$\tau_B = \eta * \left(\frac{Z_a * Z_c}{Z_b * Z_d}\right) * \tau_{in}$$

Where:

Efficiency η	0.9
Z_a slew bearing number of teeth (stage 2)	47
Z_b gear 1 number of teeth (stage 2)	15
Z_c gear 2 number of teeth (stage 1)	30
Z_d gear 3 number of teeth (stage 1)	15

This gives a total output torque of 229.3 Nm, that could be applied to the work driver.

Whilst this gear configuration can generate the required levels of torque, the amount of rotation generated would be reduced by the same ratio. Therefore, it was necessary to determine how much rotation would be needed to generate 215 Nm so the linear slide can be specified correctly for both the required force of the input toque and required displacement.

A FEA simulation was prepared consisting of the splined collet and the example splined shaft. A force of 117.8 N was then applied to each segment of the collet representing the clamping force of the work driver, with a rotational movement applied to the entire collet ranging from 0° to 1.2°. the example shaft was then held captive representing its fixing to the test rig frame. This is shown in **Figure 3** with the corresponding displacement results shown in **Figure 4**.

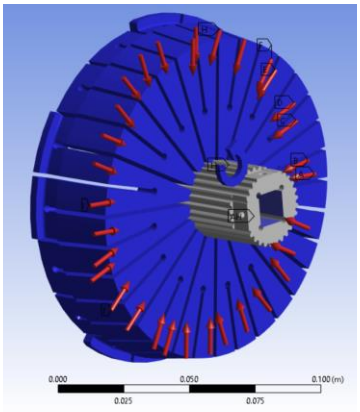

Figure 3: setup of the FEA simulation. The red arrows represent the clamping force, with the blue arrow representing the rotation of the collet

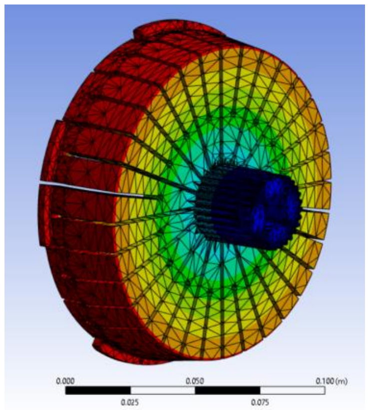

Figure 4: displacement colour map of the FEA simulation

As can be seen from results (**Figure 5**), to induce a resultant 250 Nm of torque, the collet (and thus the slew ring) will need to rotate by 1.2°. Considering the 6.2:1 gear reduction, the input shaft will need to rotate by 7.56°. Given the 0.537 m length of the lever (centre to centre) attached to the linear slide, the slide will need to displace 35.4 mm to ensure full torque is applied to the collet. This however does not take into account the backlash in the gears. This issue of backlash and general play within the drive train became apparent during the actual testing and is detailed below.

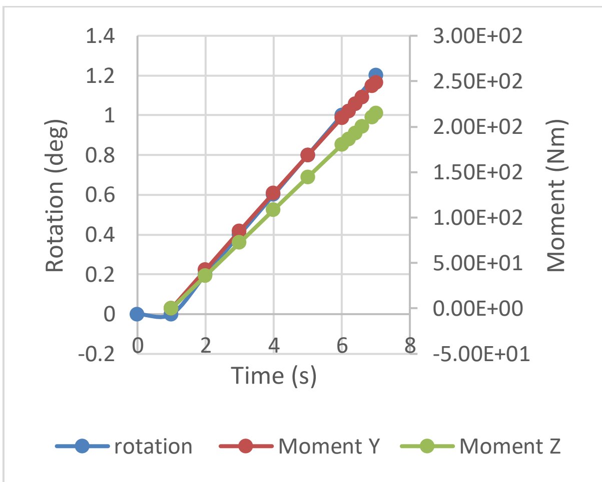

Figure 5: results of FEA simulation rotation vs induced torque

Figure 6 shows the fully assembled toque test rig.

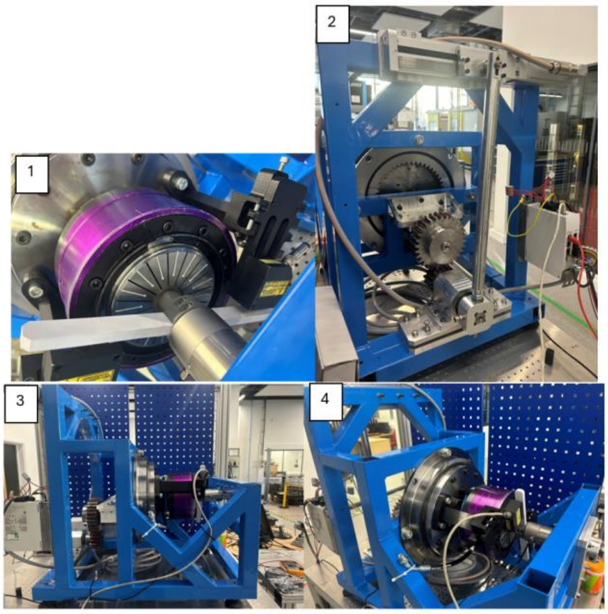

Figure 6: 1/ work driver showing torque sensor and Rifteks, 2/ linear slide and drive train, 3/ side view of test rig, 4/ front view showing work driver and slew bearing

3. Evaluation

Following the manufacture of the test rig, the example splined shaft was added to the collet and was then connected to the toque sensor. The linear rail was then jogged to induce the torque on the work driver.

However, as the rotation was added to the work driver, the Rifteks recorded rotation significantly higher than the expected 1.2° needed to induce the required levels of torque.

The work driver rotated to 2.5° whilst only small amounts of induced torque ≈ 5 Nm were observed. This was observed three times when the work driver was subjected to rotation. It was determined that due to the large amounts of torque being generated the entire frame was twisted and distorting. That coupled with the backlash in the drivetrain meant that the 100 mm of stroke supplied by the linear slide was not capable of generating the required 215Nm of torque.

In order to test the collets under the required torque, the linear slide was disconnected from the drive train and the initial force was generated manually. Ten separate tests were performed on the splined collet: five clockwise (CW) and five counterclockwise (CCW).

The first five tests performed consisted of rotating the clamp counterclockwise (CCW). Due to the manual nature of the test, it was not possible to get a consistent repeatable final value. Instead, the main aim was to apply torque until 250 Nm could be achieved. Following this the clockwise (CW) rotation tests were performed.

Figure 7 shows an example of the CCW tests. It was observed that in all tests the toque and rotation appeared to be fully elastic, with both torque and rotation retuning to zero after maximum torque has been applied. This would indicate that no plastic deformation has occurred, and that the collet can withstand the max torque applied, which is far more than the specified 215 Nm. From the five CCW tests the peak torque, and rotation values were taken and are depicted in **Figure 8**. As can be seen, all max torque values are between 290 Nm and 350 Nm, with all rotations being between 0.35° and 0.44°. This results in an average max torque applied of 322.647 Nm with an average induced rotation of 0.390°, or a rotational stiffness of 828.1 Nm/deg.

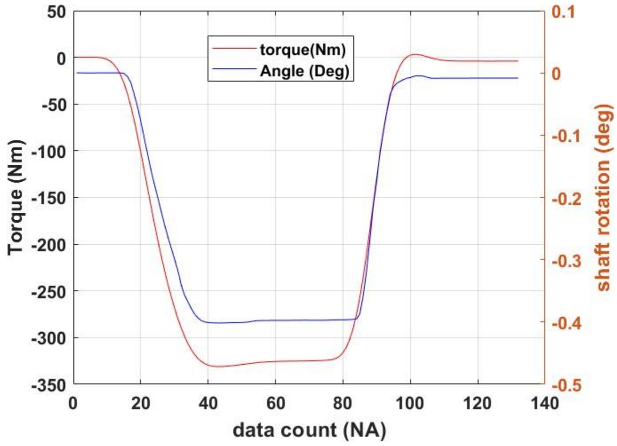

Figure 7: CCW test 1 torque and rotation results

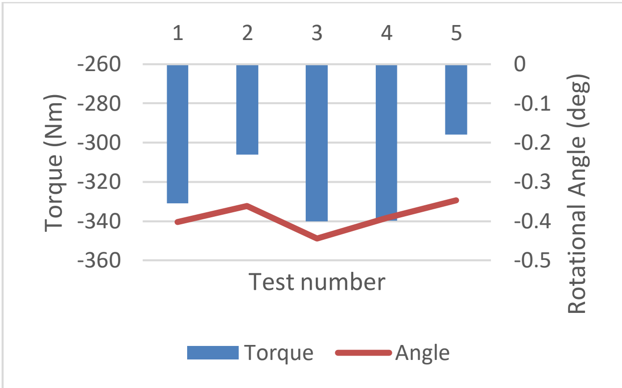

Figure 8: peak torque and max rotation results for all five CCW tests

For the clockwise (CW) tests the same process was followed. The Rifteks re-zeroed torque was again applied this time in the clockwise (CW) direction. An example result is shown in **Figure 9**, with all peak toque and max rotation values for all five tests shown in **Figure 10**. Additionally, all toque curves form all ten tests in shown in **Figure 11**.

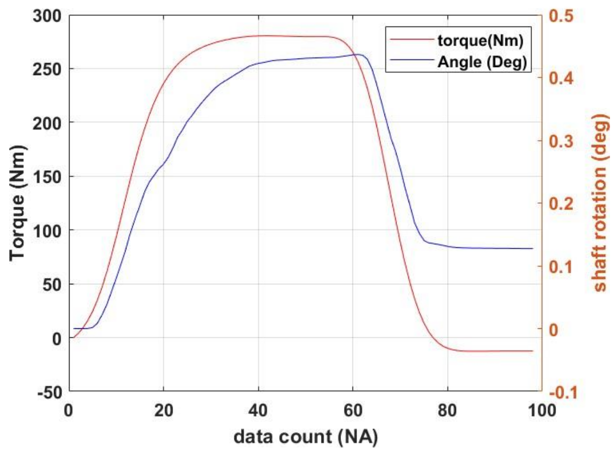

Figure 9: CW test 1 torque and rotation results

For the CW tests, whilst the toque values in all five tests appeared to return to 0 Nm, the rotation appeared not too. In tests one, two, four, and five, the rotation does not return to zero this would potentially indicate twist in collet, the chuck, or both. However, in all five cases the max torque achieved was well in excess of the required 215 Nm.

Potentially due to the twist in the setup the average max peak torque was slightly lower at 290.5 Nm with a slightly lower induction angle of 0.353°. This gives an average stiffness of 822.06 Nm/deg.

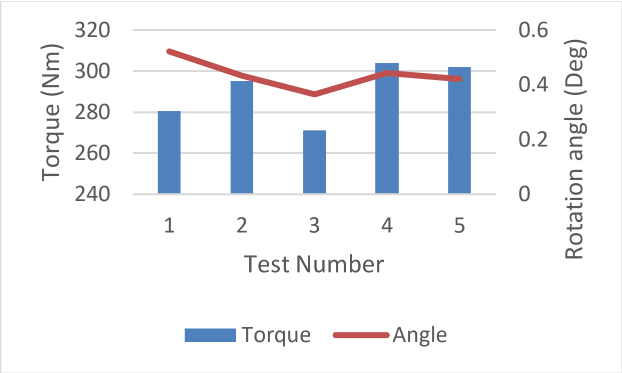

Figure 10: peak torque and max rotation results for all five CW tests

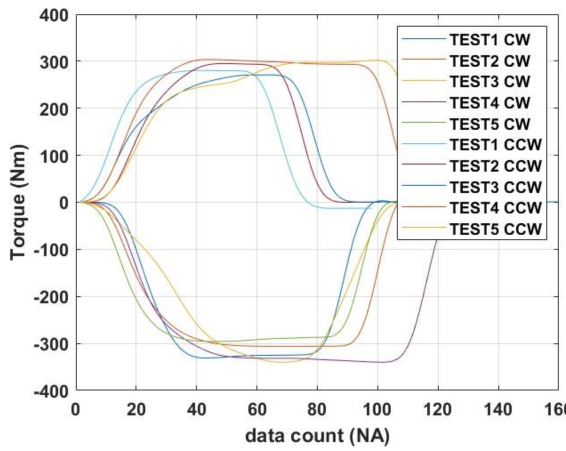

Figure 11: all torque results form 5 CCW tests and 5 CW tests

With respect to the twist of the system in the CW tests, compared to the CCW tests, a much larger difference between the two Riftek sensors was observed. As shown in **Figure 12**, the difference between the CW tests and CCW test is apparent. When looking at the difference between the two Riftek sensor results, the CCW tests has a difference of a few tenths of a degree. However, the difference in rotation in the CW test is much higher. Indicating that the collet or chuck is not rotating equalling around its centre axis. This twist could be the cause of the torque difference in the CCW and CW tests.

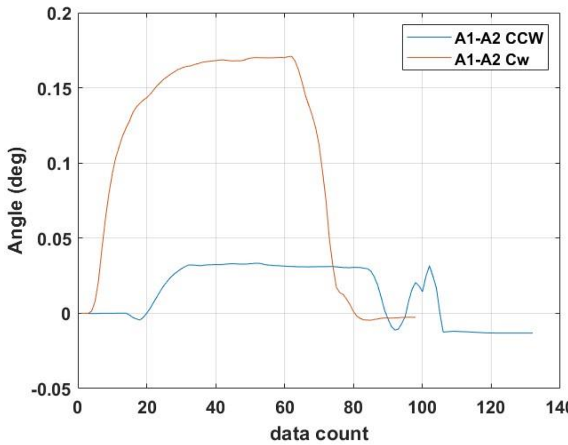

Figure 12: difference in angle between CW and CCW tests

4. Conclusion

The aim of this project was to determine whether a new style of splined collet chuck could withstand 215 Nm of torque applied from an external source. The test rig was designed to repeatedly deliver 230 Nm; however, structural twisting and gear backlash prevented the system from reaching its full potential under automated conditions.

Despite this, manually applying force at the rig's input demonstrated that it could deliver over 300 Nm of torque to the collet. Across five counterclockwise (CCW) and five clockwise (CW) tests, the results showed that the new collet design can easily endure the required 215 Nm for grinding operations, with a significant safety margin.

Furthermore, any torque applied resulted in elastic deformation only, with no signs of plastic deformation or tooth skipping observed in any of the tests.

For future use, additional work will be required on the drivetrain to ensure the rig can apply repeatable torque when operated with the linear slide.

5. Acknowledgement

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