THE COMPOSITE DISC - A NEW JOINT FOR HIGH POWER DRIVESHAFTS

Dr Andrew Pollard

Principal Engineer

GKN Technology

UK

INTRODUCTION

There is a wide choice of flexible couplings for power transmission applications, each type targeted at different areas of the performance spectrum. Selection of the most appropriate coupling is made difficult by the variation of design principle and overlapping performance specifications. Claims for new types of coupling may be met with a degree of scepticism, but GKN believe they have developed a joint which genuinely extends the performance spectrum for such joints into new areas.

The Composite Disc Joint is a new kind of constant velocity joint with characteristics originally targeted towards automotive propshaft applications, where it offers exceptionally high efficiency and suitability for high speed / small angle applications. It has a novel and complex structure of glass fibre in an epoxy matrix, with the orientations of the glass fibre reinforcement layers controlled to give the desired combination of torsional, axial and radial stiffness. Use of glass fibre in this way gives a fundamental theoretical advantage over other materials used in disc joints, which is reflected in an improved operating torque / installed angle capability.

FIGURE 1 - LCD11 and LCD34 composite disc joints

PERFORMANCE CHARACTERISTICS OF THE COMPOSITE DISC JOINT

Development has been focussed on discs with an overall diameter of 140mm (LCD11 disc) and an overall diameter of 390mm (LCD34 disc), see Figure 1. The LCD11 disc weighs 55 grammes and has achieved an ultimate torsional strength of 3000Nm, whilst the LCD34 disc weighs 390 grammes and has achieved an ultimate torsional strength of 27000Nm.

The principal competitive advantages of the joint are:

1. Suitable for high speed applications

   The composite disc has high in-plane stiffness, which in turn gives high centring stiffness without the need for an external centring device. The mounting holes are positioned to close tolerances with a close fit to the mounting bolts, so that there is no backlash and run-out is low. Low joint weight and high efficiency are also beneficial to high speed applications.

2. High efficiency, very low heat generation

   The joint shows elastic deformation with no rubbing surfaces and very low heat generation under high transmitted powers has been demonstrated.

3. Axial compliance under torque

   The joint can accommodate small axial displacements, with an axial stiffness typically in the range 100N/mm to 1000N/mm. The axial stiffness is higher for smaller discs, and increases with increased installed angle. It is virtually independent of torque in normal operating ranges.

4. Torsional fatigue endurance

   Excellent torsional fatigue; eg. the LCD11 disc, fatigue tested at amplitudes of up to ±1500Nm, has a life in excess of 1 million reversals.

5. Low weight

   In an automotive propshaft application, there is a direct weight saving of 500 grammes from substituting a 55g LCD11 composite disc for an approximately equivalent rubber coupling weighing 550g. However, there are additional weight savings due to shorter bolts, absence of a centring device and less plunge requirement for assembly. Together, these contribute to an overall weight saving of approximately 1kg. The LCD34 disc, weighing 390 grammes, is used in a wind turbine driveshaft application in place of a large constant velocity joint weighing 30 kg.

6. Zero backlash, low inertia, torsionally stiff

   The above characteristics combine to make the joint attractive for high acceleration servo drives.

7. Tolerance of hostile environments

   The glass fibre / epoxy resin composite from which the joint is tolerant of many typical aggressive environments, eg. oil, ozone, sea water etc.. The material has a particularly high glass transition temperature (above 180°C), so operating temperatures up to 100°C are acceptable and excursions above this are permitted.

8. Maintenance free

   A major advantage for many applications is the maintenance-free characteristic, which follows from the absence of lubricant or rubbing surfaces and the fatigue endurance of composite material.

The main restriction to specifying the composite disc joint, in common with all other types of flexible coupling, is its endurance under a permanent installed angle. GKN have carried out extensive finite element analysis and other theoretical work to understand the behaviour of the joint as it deforms, described in the following section.

ANALYSIS OF COMPOSITE DISC JOINT BEHAVIOUR

The deformation of a composite disc joint under combinations of angle, axial displacement and torque is complex. Finite element modelling is the most practical means of analysing its behaviour, and models have been constructed which closely represent the laminated structure of the disc and specific fibre orientations in the layers. This was achieved using composite shell elements in ABAQUS; for each shell section the thickness of each ply in the laminate is defined, together with its material properties and in-plane orientation. Where the thickness of the disc changes, tapered shells are used.

A huge amount of information is generated from the finite element model; there is potential to examine the stresses occurring at every point within the structure both aligned with and perpendicular to the fibre directions.
Figure 2 shows a contour plot of direct strain, aligned with the limbs, developed on the surface of an LCD11 disc when torque is applied. Tensile strains are represented by darker shades. It is clear that three limbs behave as tension links, whilst the other three behave as compression struts. Because the disc is thin, the compressive limbs contribute little to the ultimate torsional strength.

FIGURE 2 -
Surface strain in LCD11 disc with torque

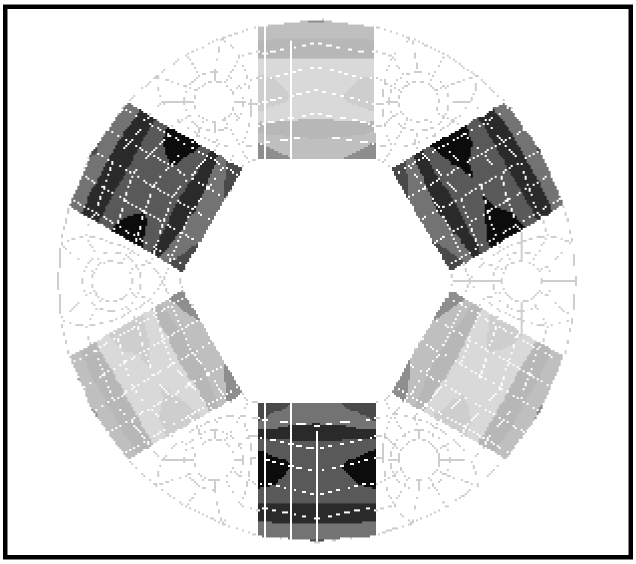


FIGURE 3 -
Surface strain in LCD11 disc with combination loading

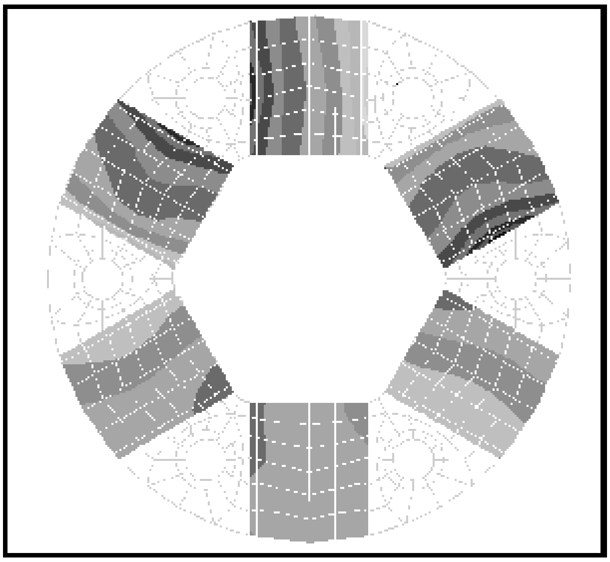


Figure 3 shows a similar contour plot, but for an LCD11 disc subjected to a combination of 1000Nm torque, 2° angle and 2mm axial displacement. Such contour plots show the strain distribution at a point in time. It is important to recognise that as the disc rotates, there is cyclic variation of the strain.

The cyclic variation of strain has been verified using strain gauges, and also represented via the finite element model. Figure 4 shows the positions of strain gauges attached to an LCD11 disc, each orientated to record the strain generated in the direction directly between adjacent boltholes. The disc was then fitted between 3-arm flanges in a test rig and rotated through one complete revolution at 2° installed angle. The strains recorded from the gauges are plotted in Figure 5, and show that each point in the disc suffers a sinusoidal variation of strain, with an amplitude and phase angle depending on position in the disc.

The finite element model was used to calculate the theoretical strain cycles corresponding to the test rig condition and Figure 6 shows the finite element prediction for strains at the gauge positions. The correlation of the curves in Figures 5 and 6 is excellent, and gives confidence in use of the technique to analyse more complex loadings.

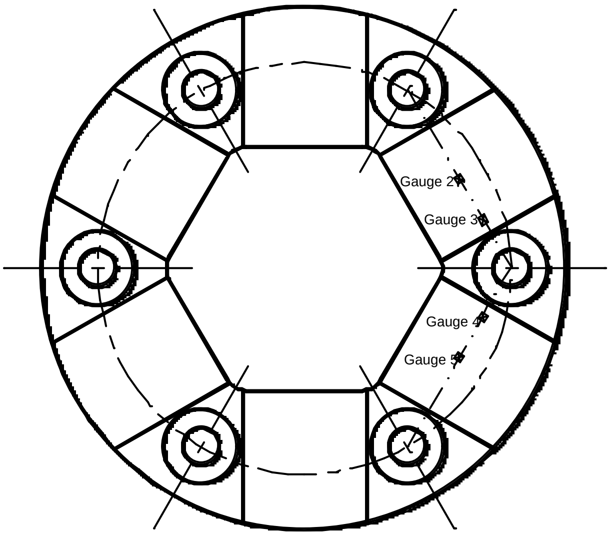


FIGURE 4 - <u>Strain gauge positions on LCD11 disc</u>

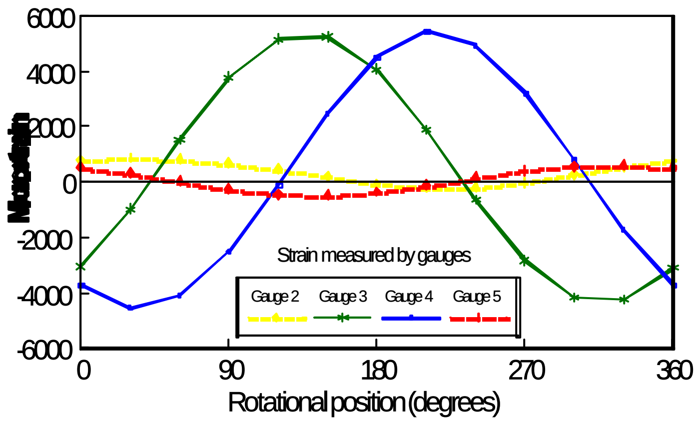


FIGURE 5 - <u>Surface strain cycle measured on test rig during rotation at 2° angle</u>

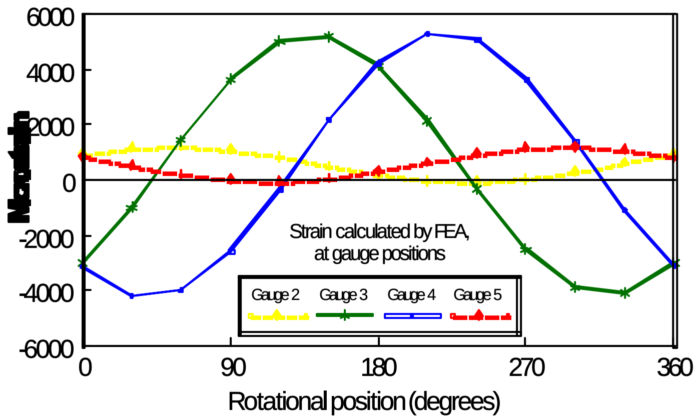


FIGURE 6 - <u>Surface strain cycle predicted by FEA for rotation at 2° angle</u>

In order to examine the strains developed during operation under severe conditions, tests were carried out with composite discs installed in the propshaft of a high power rear wheel driven car. The LCD11 disc, with strain gauges attached, was fitted to the propshaft and data telemetry was used to transmit the strain signals from the rotating shaft for logging. Figure 7 shows the recorded strain data for one complete revolution of the propshaft during an impact start (maximum shock torque) test.

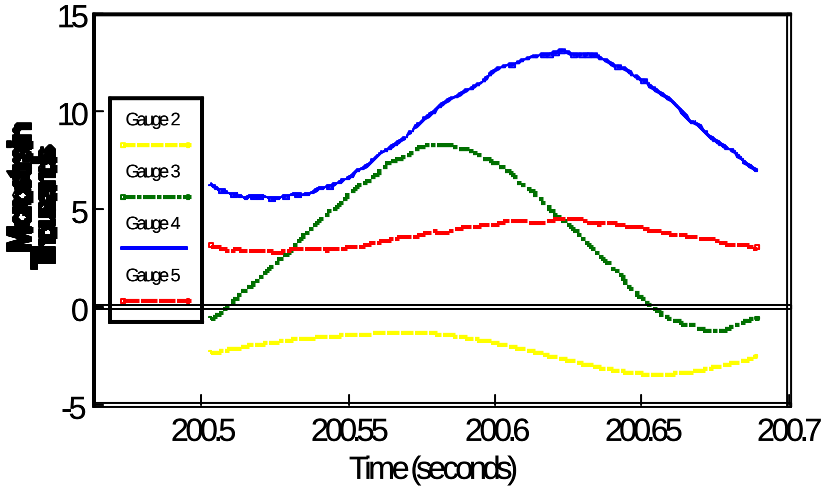


FIGURE 7 - <u>Strain gauge data recorded over one revolution of propshaft during impact start</u>

The loading on the finite element model was adjusted until the predicted strain cycle closely matched the measured results shown in Figure 7; the derived loading conditions and corresponding predicted strain cycle are shown in Figure 8. It was thus inferred that, at this point in time, the disc was subjected to a combination loading of 1163Nm torque, with 1.8mm of axial plunge and -1.3° installed angle. The technique provides valuable insight into transient load conditions imposed on the disc, and the overall performance spectrum required to meet an installation requirement.

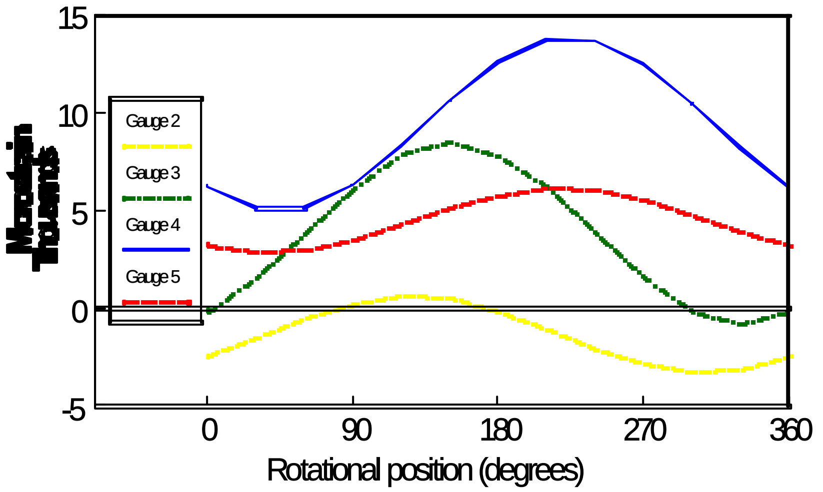


FIGURE 8 - <u>Strains at gauge positions determined by FEA under inferred impact start loading</u>

DEVELOPMENT OF COMPOSITE DISC FOR WIND TURBINE DRIVESHAFT APPLICATIONS

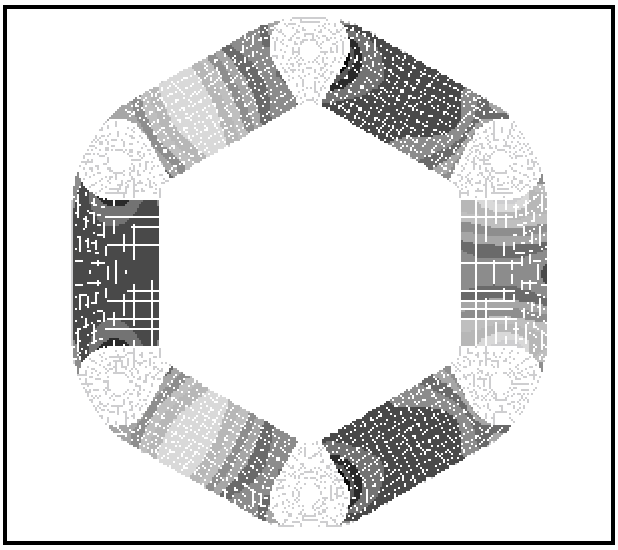
The market for wind energy generators has developed strongly through the 1980's. By 1990, the total world wind power capacity was 2000MW, increasing to 4300MW by 1995 and forecast continued doubling over each 5 year period through to 2020.

Wind turbine technology is developing very rapidly because of the commercial benefits that arise from increased size and improved efficiency. The typical installed power of turbines in the early 80's was a maximum 100KW, rising to 300KW by 1990 and 600KW currently. The major producers are now introducing turbines of 1500KW output, and this kind of power output is forecast to be the norm by 2005. A 1500KW turbine typically employs a 3 bladed rotor of around 60 metres diameter rotating about a horizontal axis at the top of a tower 60 metres high. The rotor output is taken through a 1:80 ratio gearbox to increase the speed to 1500 rev/min and by an interconnecting shaft to a generator. The majority of wind turbines installed throughout the world are manufactured in Denmark.

As the demand for higher power output has developed, the efficiency of the joints in the interconnecting shaft has become a principal design requirement. The joints must accommodate small movements of the gearbox and generator on their mountings; the compliance of the structure in which they are mounted is also significant given the high operating torques. Very high efficiency must be maintained in order to avoid overheating of the joints during periods when high power outputs are sustained, and it has been found that constant velocity joints are not viable for 1500KW applications.

The LCD11 composite disc joint had demonstrated high efficiency in rig tests for automotive propshaft applications, and in 1995 a development programme was started to produce a joint for the wind turbine application. GKN's operating company in Denmark, Dansk Uni-Cardan, had already established business in driveshafts for turbines and had a good understanding of the operational requirements. The first prototype LCD34 joints were installed in a 1500KW turbine in the autumn of that year.

Finite element analysis was used to introduce design improvements for the LCD34 disc. The stresses occurring in the core of the limbs (aligned with the fibre direction) under a typical operating condition are shown in Figure 9. As described previously, the severity of this loading can be assessed by using FEA to derive the cyclic variation under rotation. The shape of the limbs and fibre layup were modified in order to improve the performance of the disc under combined angle and torque, the comparable contour plot for the improved design is shown in Figure 10. The overall performance diagram of the joint can be mapped from the finite element analyses.



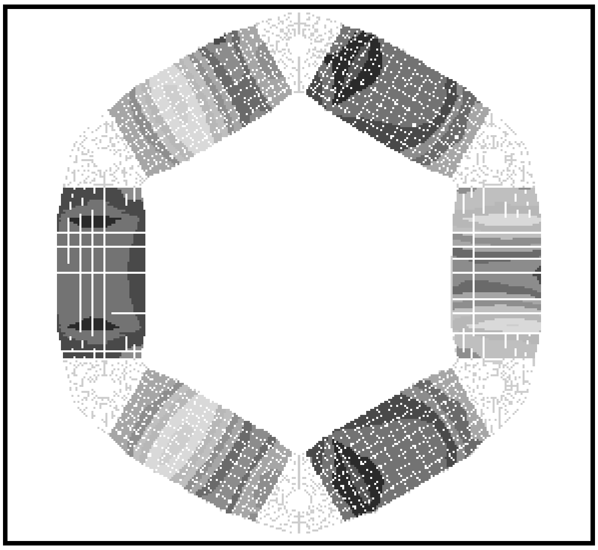


FIGURE 9 - <u>FE contour plot for original LCD34 disc</u> *FIGURE 10 - <u>FE contour plot for improved LCD34 disc</u>*

Results from tests of the prototype composite disc joints in the application were positive and led to composite disc interconnecting shafts being specified for 1500KW turbines commercially introduced in 1997 (Figure 11).

GKN are active in the use of Life Cycle Analysis to assess the environmental impact of their driveshaft products, and an LCA is being conducted for the composite disc joint. The low mass of the joint and the consequent low use of energy in manufacture are favourable, likewise its high efficiency and low maintenance requirement are beneficial during the service phase.

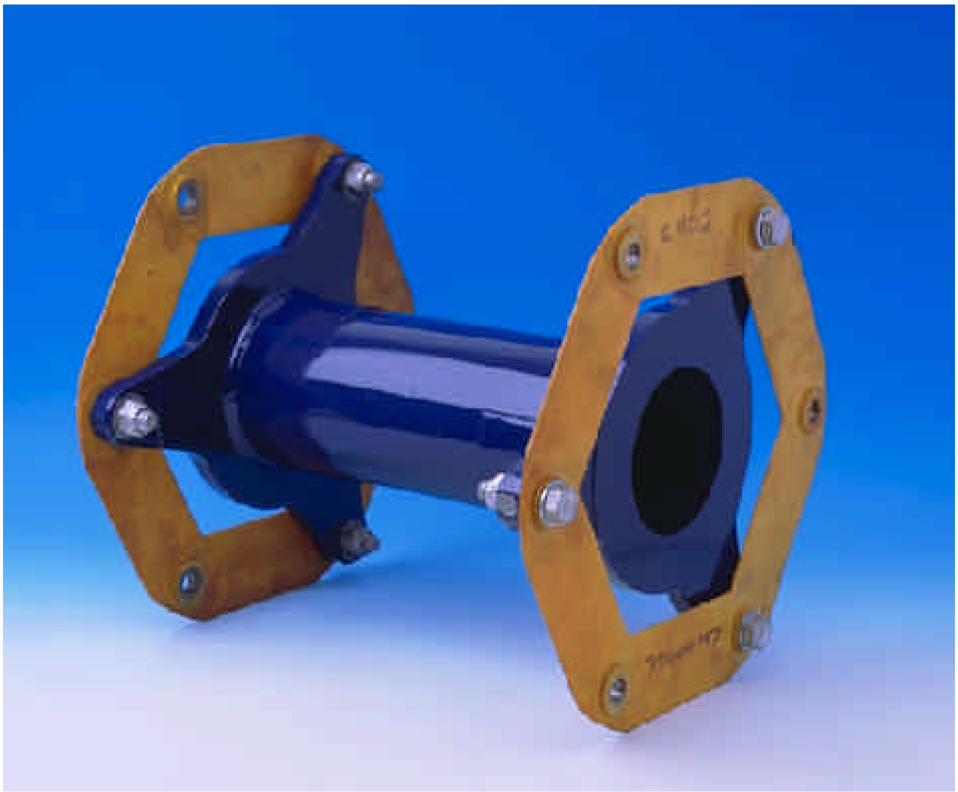


FIGURE 11 - Intermediate shaft with composite disc joints supplied to 1500KW wind turbine

CONCLUSIONS

The composite disc is a joint of very low mass which is effective for very high transmitted powers. Finite element analysis has proved to be an effective means of analysing and understanding the behaviour of the disc, and will continue to be used to support development of the disc for new applications.

Successful introduction of the composite disc joint to the wind turbine application has demonstrated an effective solution to a demanding technical requirement.