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INDEXING GEARBOX CAROUSEL HYBRID DISC MANUFACTURING

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Abstract: *The paper focuses on the manufacturing of a hybrid carousel disc for an indexing gearbox, developed to reduce the mechanism mass and improve its dynamic performance. It describes the manufacturing chain, including composite material definition, the design and fabrication of a mould from tooling board, and compression moulding technology. Furthermore, the study analyses technological aspects of machining abrasive GFRP/CFRP materials, including the selection of cutting conditions and tools, and the integration of steel inserts, which requires precise surface preparation and verification of adhesive bond quality. The work refers to FEA results for mass moment of inertia and natural frequencies as the basis for validating the proposed manufacturing solution. The presented know-how demonstrates the technological feasibility of the hybrid concept and provides a foundation for subsequent operational testing and patent-protected implementation.*

Keywords: Indexing gearbox, Carousel disc, Compression moulding, Short-fibres composite, Hybrid structure

1. Introduction

Hybrid structures are widely used in composite engineering to achieve the required mechanical properties (stiffness and strength) and/or dynamic performance. This approach enables the combination of the toughness of metals with the high specific stiffness and fatigue resistance of fiber-reinforced polymers (FRP). In general, a hybrid design is most beneficial when the global requirements favor a composite solution (e.g., stiffness, dynamics, fatigue resistance), while local functional requirements call for metallic features (e.g., dimensional accuracy, bearing and contact surfaces, etc.). Typical applications include rotating joints and structural 'nodes', where cyclic contact and wear occur; such conditions can be critical for the metal–composite interface and may govern the service life of the structure.

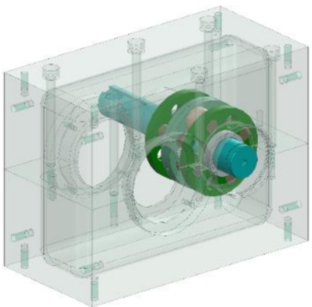

Fig. 1: Original 'steel' carousel assembly in indexing gearbox housing.

Hybrid structures offer lower mass, higher specific stiffness and strength, improved dynamic behavior (vibration response and damping), and enhanced fatigue resistance and damage tolerance. However, the interface between dissimilar materials is a key risk area, particularly with respect to galvanic corrosion in the presence of carbon fibers, mismatched coefficients of thermal expansion, and environmental effects (salts, moisture, temperature, UV exposure, and chemicals). These issues impose stringent requirements not only on the overall hybrid design but also on manufacturing discipline, especially at the material

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interface. The joints should be designed to be loaded predominantly in shear. Prior to bonding, the metal surface must be roughened and thoroughly degreased, and mechanical locking/fastening is also commonly employed to enhance joint reliability in hybrid assemblies.

In the case of the carousel disc of the indexing gearbox, whose CAD model is shown in Figure 1, the cam-induced loading is favorable for the use of a hybrid structure. The material interface is loaded predominantly in compression, acting exclusively in the direction normal to the bonded surface. The use of a composite is also well suited to the cyclic loading conditions of the mechanism.

2. Composite material

The elastic properties of a short-fiber composite can be analytically predicted using the Fox–Krenchel model, which is a modification of the Rule of Mixtures (RoM) model for continuous fibers:

$$E_L = E_m \cdot V_m + \eta_l \cdot \eta_{o,E,L} \cdot E_f \cdot V_f \quad (1)$$

$$\frac{1}{E_T} = \frac{V_m}{E_m} + \frac{V_f}{\eta_l \cdot \eta_{o,E,T} \cdot E_f} \quad (2)$$

$$\frac{1}{G_{LT}} = \frac{V_m}{G_m} + \frac{V_f}{\eta_l \cdot \eta_{o,G} \cdot G_f} \quad (3)$$

$$\nu_{LT} = \nu_m \cdot V_m + \eta_l \cdot \eta_{o,\nu} \cdot \nu_f \cdot V_f \quad (4)$$

where the analytical Cox shear-lag model describes the transfer of load from the matrix to a short fiber through interfacial shear:

$$\eta_l = 1 - \frac{\tanh\left(\frac{\beta l}{2}\right)}{\frac{\beta l}{2}} \quad (5)$$

$$\beta = \sqrt{\frac{2 \cdot G_m}{E_f \cdot r^2 \cdot \ln\left(\frac{R}{r}\right)}} \quad (6)$$

$$\mathrm{R} = \frac{r}{\sqrt{V_f}} \quad (7)$$

The Krenchel efficiency factor is the product of the fiber length efficiency factor and the fiber orientation efficiency factor:

$$\eta = \eta_l \cdot \eta_o \quad (8)$$

where individual efficiency factors are:

$$\eta_{o,E,L} = \cos^4(\theta) \quad (9)$$

$$\eta_{o,E,T} = \sin^4(\theta) \quad (10)$$

$$\eta_{o,G} = \cos^2(\theta) \cdot \sin^2(\theta) \quad (11)$$

$$\eta_{o,\nu} = \cos^2(\theta) \quad (12)$$

The disc composite is designed using short carbon fibers and an epoxy resin with a fiber volume ratio of 55 %. Alternatively, short glass fibers may also be used. These elastic properties are used for material definition in finite-element simulations.

3. Compression moulding

The suitable manufacturing technology for this application is compression molding. This process uses compression of long fibers (up to 20 mm long) impregnated with epoxy resin in closed mold. Hybrid disc is designed for standard modulus carbon fibers – virgin carbon chopped tow of consistent length of 12 mm. (Easy Composites, 2026) The first prototypes are made of chopped glass fiber GRC Concrete ZR 12 mm. (Synthetika, 2026) Epoxy resin LH 385 with hardener H 286 is used as a matrix. (Havel-

Composites s r. o., 2026) Its viscosity is 400–800 mPas/25°C and pot life is 90 min. Mold is machined of EdaBoard EP 978 with density of 680 kg/m^3. (Ebalta, 2026) Mold surface is treated with a liquid Sealer 02, which creates smooth and glossy surface.

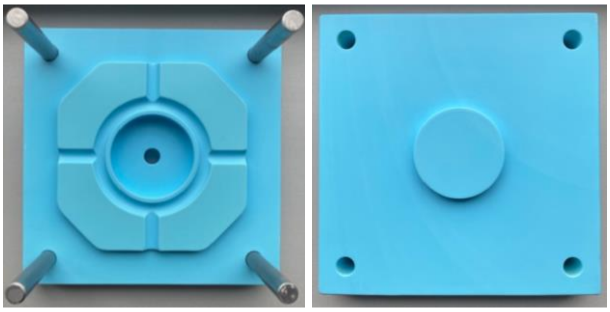

Fig. 2: Mold.

A single mold enables production of discs in the low tens, if the mold's surface is properly coated with a released agent after each use. Used released agent is CR1 Easy Release. The pressure to close the mold is First set of composite disc prototypes show fiber volume ratio of 51–59 %, which corresponds with suggested fiber volume ratio of 55 %.

4. Machining of composite

Machining is technologically demanding primarily due to the pronounced abrasiveness of glass fibres and the heterogeneous microstructure of the material. During drilling and milling, typical damage mechanisms include entry/exit delamination, fibre pull-out, local matrix peeling, and burr formation, while edge quality strongly depends on fibre orientation and local fibre concentration. From the standpoint of process parameters, it is critical to limit axial forces (especially in drilling) through appropriate tool geometry, feed optimization, and the use of backing support or double-sided clamping to reduce exit delamination; at the same time, rapid cutting-edge wear must be expected, so PCD/diamond-coated tools or cemented carbide with a wear-resistant coating are preferred. Thermal effects are significant for the epoxy matrix. Local overheating can lead to matrix degradation and reduced hole tolerance. Therefore, cutting conditions should be controlled to minimize friction and heat accumulation Because GFRP machining generates fine dust and fibrous particles, effective extraction and occupational hygiene measures are essential.

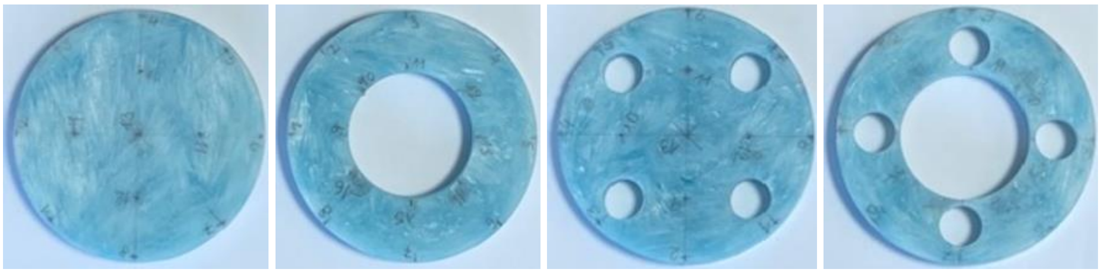

Fig. 3: Machined composite body of hybrid disc.

In this case, the composite was machined on an SLV EDU universal 3-axis milling machine with accuracy of 0.04 mm. The spindle speed ranged from 100 to 24 000 rpm. Cylindrical cutter Fraisa AX-NV3 (diameter 4 mm) was used. The feed rate was 1 500–2 000 mm/min with a material removal of 0.4 mm. It was demonstrated that, in the critical region between the flange and the insert, machining did not damage the thin laminate wall (1 mm). The machined composite surface was smooth, with no significant edge damage at the hole perimeters.

5. Inserts

Inserts are used to carry localized contact loads and to ensure dimensional accuracy. Joint reliability is governed by the adhesion and cohesion of the bonded interface: after drilling, the composite hole is lightly roughened and thoroughly degreased, while the steel insert is activated by grinding, degreasing, and, where appropriate, by applying a primer. A toughened epoxy adhesive with a controlled bond-line thickness is used to minimize stress peaks and to promote predominantly shear load transfer. It is critical to prevent air entrapment during insertion, to maintain coaxiality of the insert with the subsequent drilling operation, and to control the curing cycle, since mismatched thermal expansion and environmental effects (moisture) can degrade the interface over time and trigger local debonding.

Fig. 4: GFRP with bonded-in steel drill bushings.

6. Disc performance

The mass of the original steel disc is 0.19 kg, whereas the mass of the redesigned hybrid disc is 0.08 kg. The mass moment of inertia of the original disc about the axis of rotation in the mechanism is 188 kg·mm², while that of the hybrid disc is 61 kg·mm². Table 1 summarizes the natural frequencies of both disc variants.

Tab. 1: Natural frequencies of steel and hybrid disc (V_f = 55 %).

	Steel	**E-glass**	**Carbon**
1st mode	4 161 Hz	3 782 Hz	5 586 Hz
2nd mode	5 197 Hz	4 115 Hz	6 229 Hz
3rd mode	9 550 Hz	7 794 Hz	10 200 Hz
4th mode	12 980 Hz	9 137 Hz	14 430 Hz

7. Conclusions

The theoretical FEA results (Ch. 6), together with the validated manufacturing process, provide a strong basis for successful implementation of the proposed concept. After the hybrid carbon-fiber discs are manufactured, the carousel will be tested on a rig simulating real operating conditions to verify the mechanical and dynamic performance as well as the service life. The above-described solution is protected by several patents. The polygonal joint itself is protected by Patent CZ 306709, and the entire hybrid disc solution is protected by Patent CZ 310532 B6. Technology and application of the hybrid disc are under utility model no. CZ 38182 U1 protection.

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