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TRANSVERSE KEY VS SPLINE SHAFT: EFFICIENCY AND DESIGN TRADE-OFFS IN TORQUE TRANSMISSION

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Abstract: This research evaluates transverse keys against various spline connections for torque transfer efficiency. Fine splines demonstrate superior performance overall, while transverse keys offer competitive advantages for narrow hubs and cost-sensitive applications. The findings guide designers in selecting suitable connection types based on torque requirements, manufacturing complexity, and practical constraints.

KEYWORDS: transverse key, spline shaft, torque transfer, fine spline, involute spline, straight-sided spline

1 Introduction

The study by [1] presents a novel approach to torque transmission using a feather key positioned transversely relative to the rotational axis, resembling the configuration of a pin joint. The transverse key can be configured in two distinct orientations - type 1 and type 2 - depending on the key's rotational placement. According to the findings, this method achieves favourable results concerning maximum transmissible torque, particularly when applied to hubs with small widths. However, a significant limitation is that this approach can only be implemented at the shaft's edge surface.

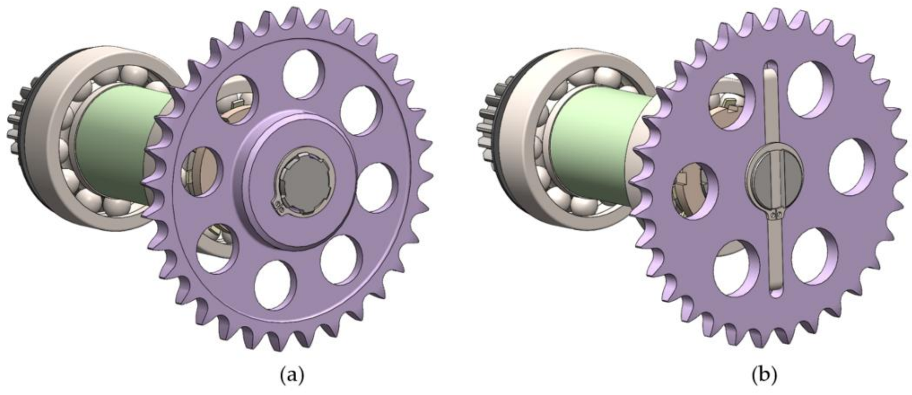

Fig. 1 - Gearbox Shaft Example; spline connection (a), transverse key type 2 connection (b)

Spline connections are commonly utilised for transmitting substantial variable and impact torque loads [2, 3]. These connections are produced in three primary configurations: straight-sided splines, fine splines, and involute splines. An advantage of spline connections is their capability to permit axial movement of the hub along the shaft, as well as their ease of disassembly, which explains their widespread application, for instance, in shaft couplings between tractors and agricultural machinery [3-6]. The geometric shapes and dimensions of splines and their teeth are specified in standards [7-12].

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Figure 1 illustrates a practical implementation of a straight-sided spline and a transverse key, used for securing a sprocket onto a gearbox shaft.

As highlighted by the study [1], the transverse key demonstrates its highest effectiveness when employed with hubs of narrow width. Nevertheless, it is generally acknowledged that spline connections can accommodate significantly higher loads. Typically, the recommended spline length should range between 1.2 to 2 times the shaft diameter, except in the case of fine splines [6, 13, 14]. Despite this guideline, our research aims to investigate spline connections under conditions involving narrow hub widths. The primary objective is to assess whether employing spline connections on short surfaces offers practical advantages, or whether the transverse key method represents a superior alternative.

2 Analytical Comparison

The comparison involved connections using transverse keys (type 1 and type 2) as well as spline connections - straight-sided spline, fine spline, and involute spline. According to the standard for involute splines, two tooth module sizes can be selected; calculations were performed for both sizes. Analytical equations for transverse keys were adopted from the study [1]. For spline connections, widely recognised equations regularly used by designers were employed [13, 14].

In designing transverse keys, shear stress, shaft pressure, and hub pressure are verified. For straight-sided splines, shear stress, bending stress, and contact pressure (on the tooth's side surface) are checked. These same parameters apply to involute splines. For fine splines, shear and bending stresses are minimal; therefore, only contact pressure is verified [13,14].

From the equations, the maximum transmissible torque was derived to ensure allowable stress values are not exceeded.

Given that spline connections are typically used in stressed joints [2-6], it is assumed that shaft and hub materials are both steel. To simplify the comparison, it was assumed that both shaft and hub are manufactured from identical materials. The study [1] indicates limited value in investing in higher-grade materials, as their allowable stresses considerably exceed those of the key, which is usually the first to fail. Therefore, only two types of steel were compared: C16E (equivalent to 12 020 according to the older STN designation) and C55 (equivalent to 12 060).

According to STN standards [15], the allowable compressive stress for C16E is 75 MPa. This value is used as a parameter in calculating torque based on pressure for both transverse key types (shaft and hub pressure), and for fine spline, straight-sided spline, and involute spline. The allowable bending stress for C16E is 80 MPa, used in verifying straight-sided spline and involute spline. The allowable shear stress for C16E is 33 MPa, whereas the permitted shear stress for the key material (E355) is prescribed as 70 MPa. All values were chosen for alternating load conditions. Allowable stresses for C55 are: compressive 110 MPa, bending 85 MPa, and shear 50 MPa.

Six variants were created based on changes in joint dimensions. Hub dimensions were selected as twice the shaft diameter, and hub width was chosen based on the appropriate key width plus 2 mm. Key lengths for transverse keys type 1 and type 2 were chosen to maximise the length given the hub diameter. All dimensions are listed in Table 1.

Figures 2 to 7 present graphs displaying the results for individual variants and compared methods. Due to scope limitations, results for C55 steel are presented only for variants 1 to 3.

Table 1 – Dimensions for each variant.

Dimension [mm]	Variant 1	Variant 2	Variant 3	Variant 4	Variant 5	Variant 6
Shaft diameter	17	20	25	30	55	90
Hub diameter	34	40	50	60	110	180
Hub width	8	8	10	12	18	27
Key length (for type 1)	32	40	50	60	110	180
Key length (for type 2)	28	32	40	50	100	160

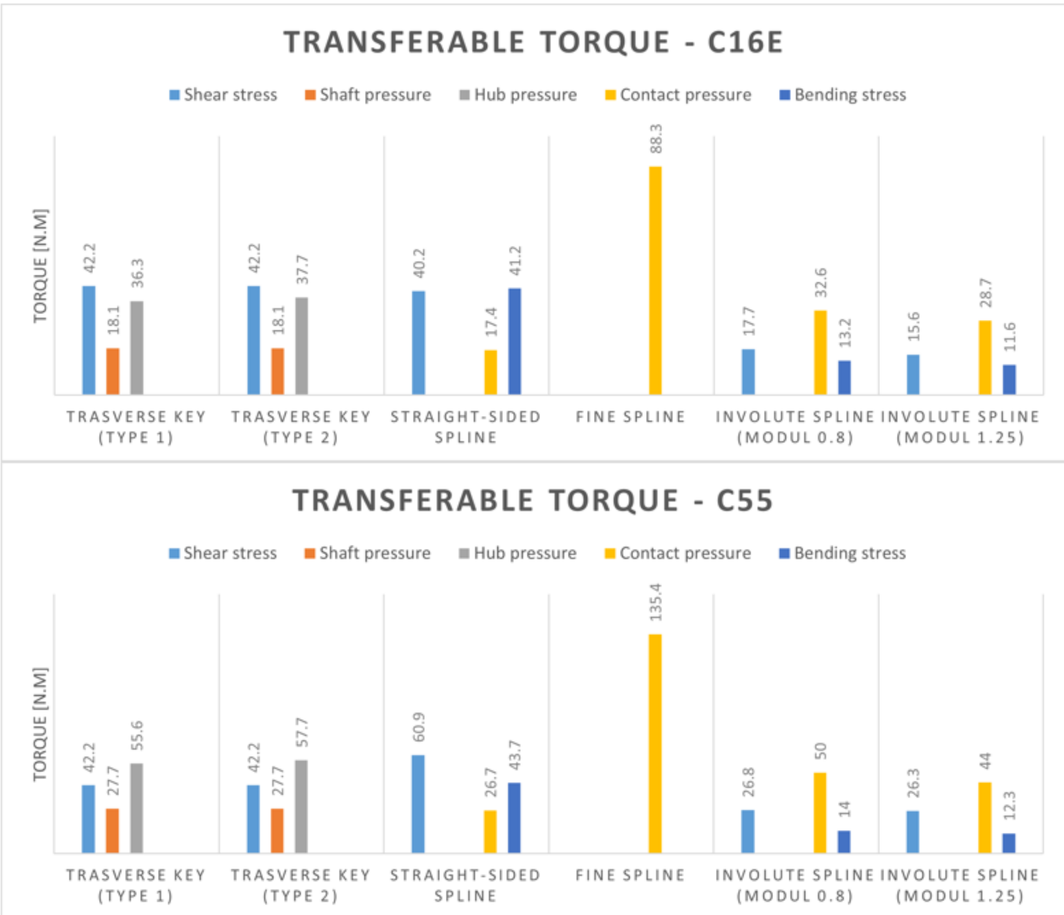

Fig. 2 – Variant 1: Graph of transferable torques using C16E steel (up); using C55 steel (down)

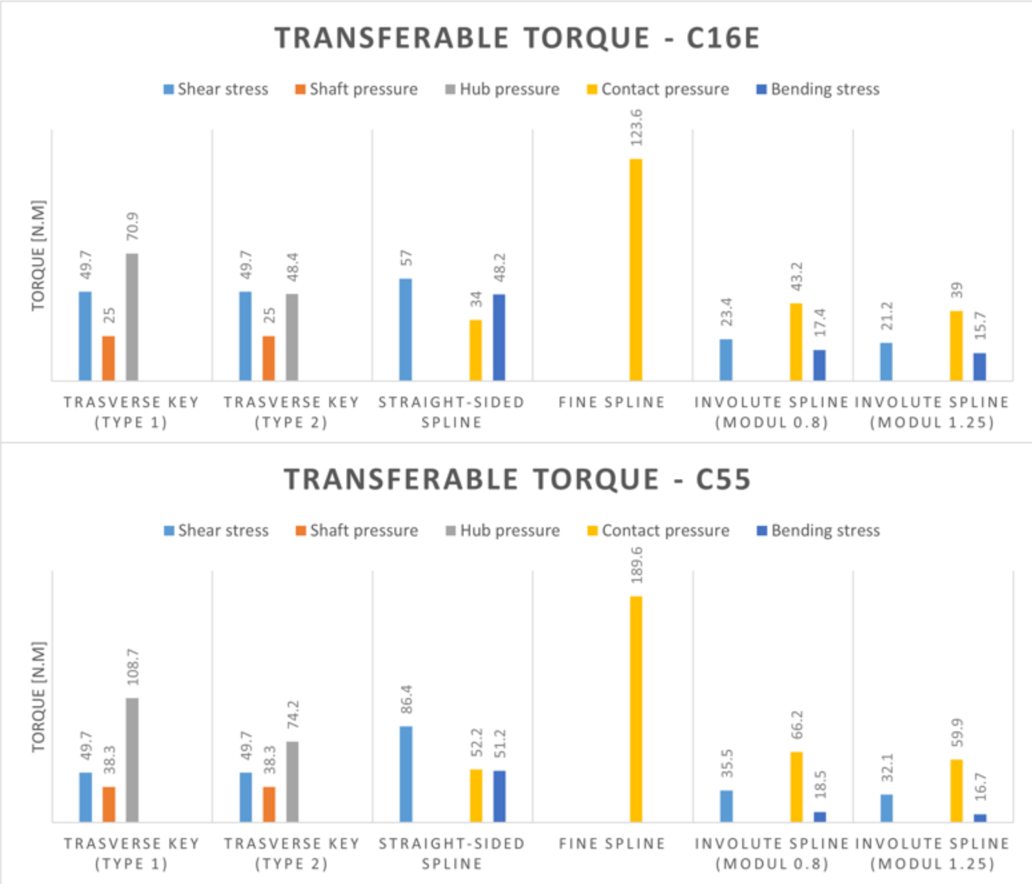

Fig. 3 Variant 2: Graph of transferable torques using C16E steel (up); using C55 steel (down)

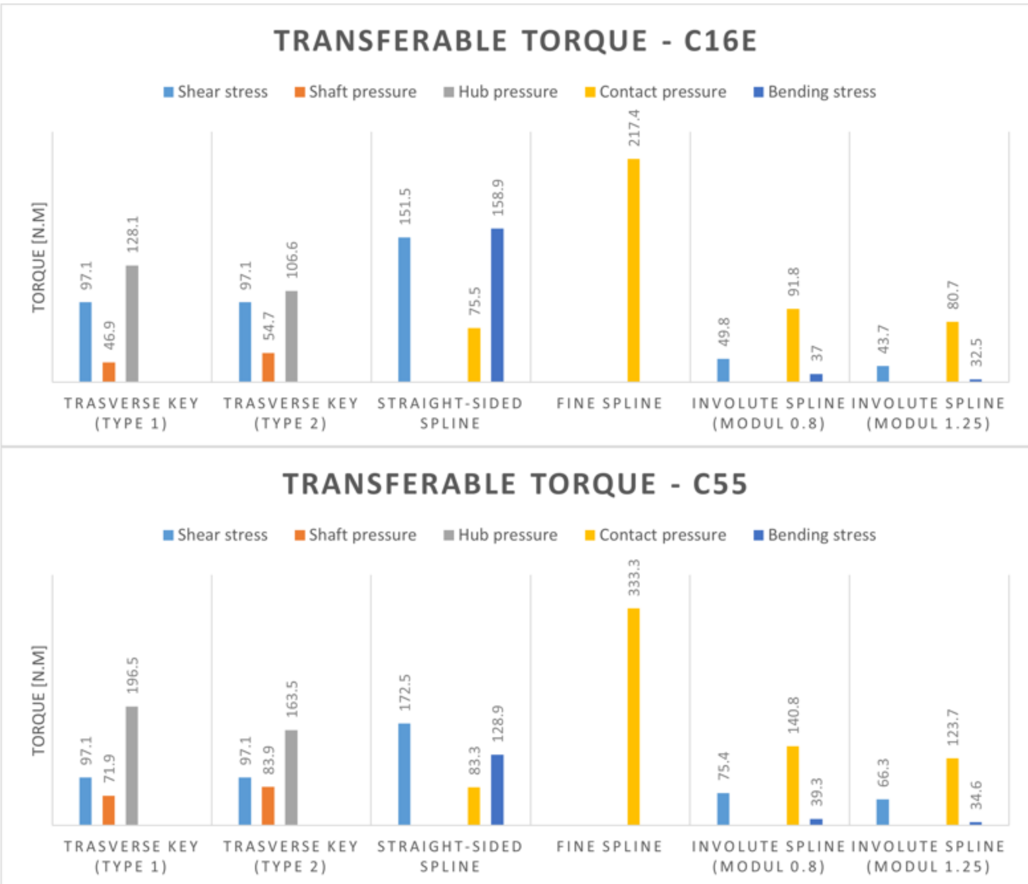

Fig. 4 Variant 3: Graph of transferable torques using C16E steel (up); using C55 steel (down)

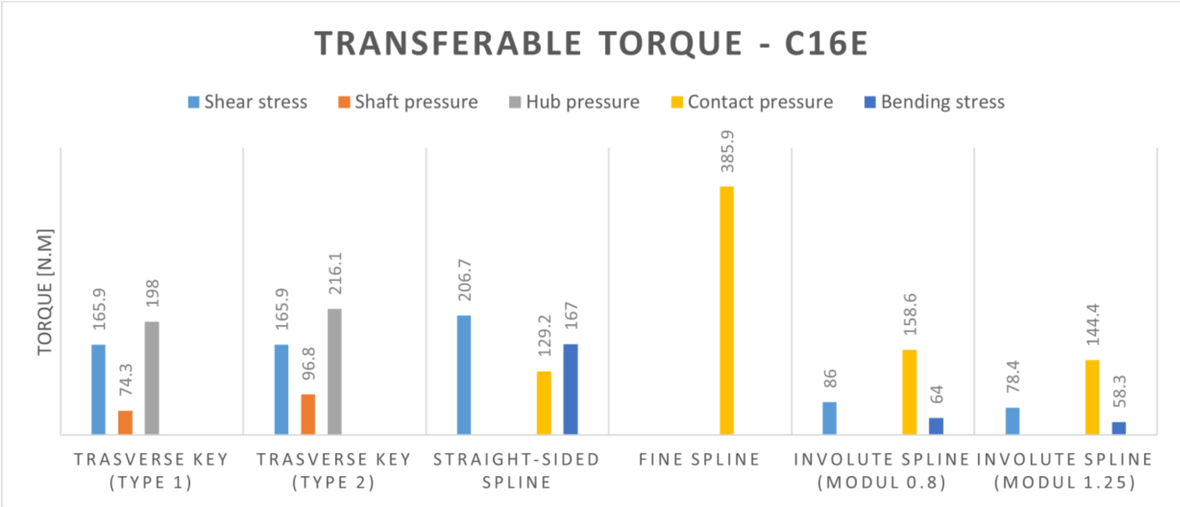

Fig. 5 Variant 4: Graph of transferable torques using C16E steel

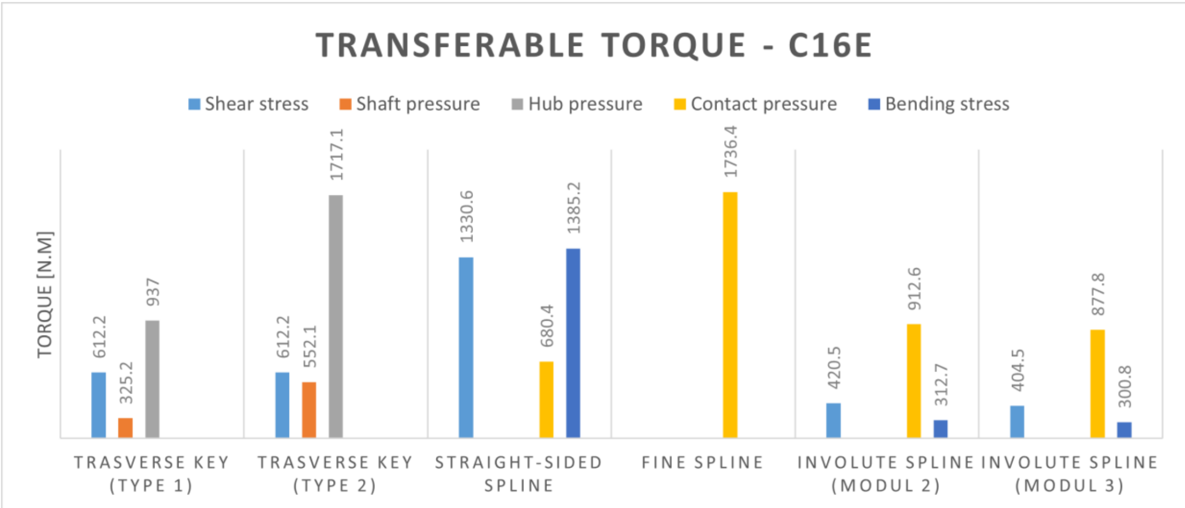

Fig. 6 – Variant 5: Graph of transferable torques using C16E steel

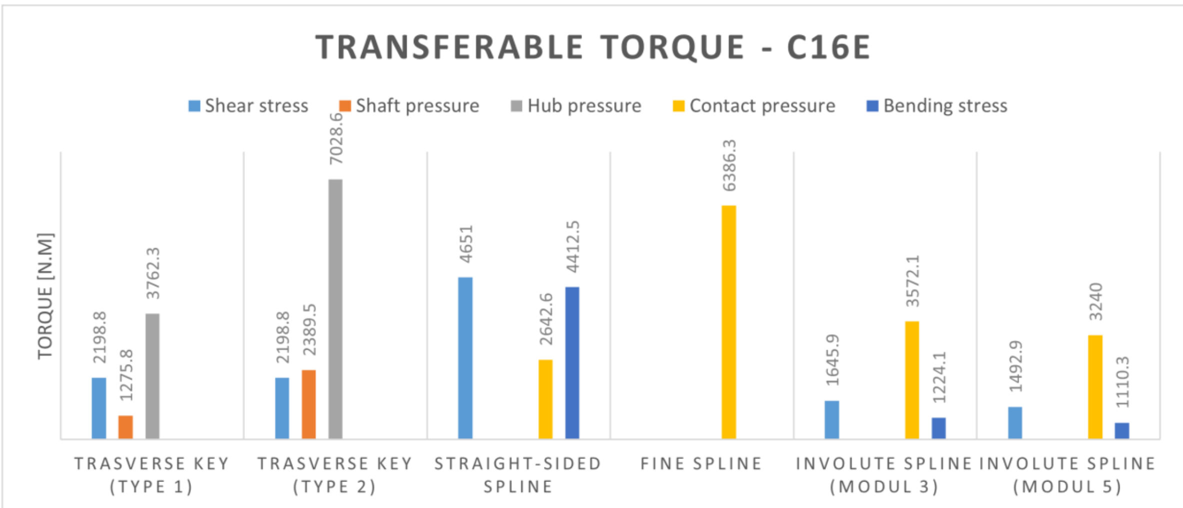

Fig. 7 – Variant 6: Graph of transferable torques using C16E steel

3 Discussion

The results clearly indicate that fine spline connections achieve the best performance across all evaluated scenarios. Conversely, involute spline connections consistently yield the lowest torque transmission values, primarily due to their lower allowable bending stress. Interestingly, the type 2 transverse key and the straight-sided spline display relatively similar torque transmission capacities. However, this similarity diminishes with larger shaft diameters due to the limiting properties of the key material itself.

Spline connections offer significant advantages, particularly in high-torque transmission and ease of disassembly. Nevertheless, when a narrow hub width is required - either due to dimensional constraints or weight considerations - the transverse key method emerges as a viable alternative, as the maximum transmissible torque is comparably effective. However, the transverse key is less suitable for frequently disassembled connections.

Manufacturing costs must also be taken into consideration. A splined hub can be economically produced using a broaching tool [16-18], whereas shaft splining typically requires shaping or milling, potentially raising production costs. As demonstrated by study [1], the manufacturing costs associated with transverse keys can, in certain scenarios, be more favourable than those for conventional feather keys. Consequently, it is reasonable to assume that production costs for transverse keys might be lower than those for spline connections. Nevertheless, assessing these costs comprehensively is complex, as they depend significantly on individual manufacturing capabilities, available equipment, and shaft dimensions.

Overall, the findings suggest that the transverse key method is a robust alternative for torque transmission, despite its inherent limitations. Given the complexity and numerous influencing parameters, it remains the designer's responsibility to determine the most appropriate method for a specific application.

CONCLUSION

This study indicates that although spline connections typically excel in torque transmission and ease of disassembly, transverse keys (especially type 2) offer competitive performance for applications involving narrow hubs. The transverse key method, while not optimal for frequent disassembly scenarios, may provide significant advantages in terms of reduced manufacturing costs compared to traditional spline methods. Ultimately, the decision between transverse keys and spline connections depends on specific application requirements, highlighting the importance of careful consideration of design constraints, cost implications, and desired performance characteristics.

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