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A Comprehensive Study of Cardon Shaft Using Modal Analysis

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***Abstract:** A rear-wheel-drive vehicle's Cardan shaft, a rotating shaft that transfers power from the engine to the differential gear, must work via continually shifting angles between the gearbox and axle. Due to the constant rotation, there is significant vibration on it. Due to this issue, the shaft frequently bends or deforms. Vibration in the Cardan shaft is a significant issue. In the present work, three distinct geometries—circular cut, rectangular cut, and no-cut—were modelled using SolidWorks software. Modal analysis was then carried out to obtain the deformation and natural frequency of all the CAD models for comparison. In the current investigation, the rectangular cut model, which produces the least deformation and natural frequency, was designated as the superior model.*
***Keywords:** Cardon Shaft; Deformation, Natural Frequency; 3D Model, Modal Analysis.*

I. INTRODUCTION

Heavy-duty vehicles, aviation, and the worldwide maritime industry are just a few examples of industries that regularly use flexible Cardan shaft systems (figure 1), which make it easier to transmit the motion of parallel or misaligned shafts. It has been researched using many mathematical models and is one of the crucial parts of a mechanical system because it is a part of the rotating machinery. [1] illustrates the model's thorough historical analysis. However, even in the case of linear motion, these models made up of a single or double universal joint (Hooke's joint, U-joint, or Cardan joint) are complicated. Therefore, to estimate the self-excited vibration and transient responses of the drive system under parametric fluctuation as well, discretization techniques like the Taylor-McLaurin series, a trustworthy numerical technique called the monodromy matrix [2, 3], and Lyapunov exponent or averaging method [4-6] have been proposed.

Figure 1: Cardon Shaft

The primary focus in the early years [7, 8] was on the parametric instability in a multibody shaft system stimulated by universal joints for various complex rotor-bearing systems. The aforementioned investigation was focused and efficient for a linear system. The lumped mass model has been taken into consideration in several research to try and distinguish the parametric excitation in a Cardan shaft by building as much as feasible a mathematical model that might actually represent the real physical system [9, 10]. The dynamic vibration and the natural frequencies of the linked shaft system were shown to be overestimated when using such a basic rotating shaft-disc model. This faulty analysis made the Cardan shaft oscillation one of the most frequently misunderstood problems [11].

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Numerous theoretical and numerical works that emphasize nonlinear parameters and show various nonlinear phenomena and parametric excitation have been published [12–14]. Cardan shaft dynamic analysis, however, heavily relies on nonlinear effects, such as breathing cracks on connected shafts caused by a Hooke's joint, which have been examined in [15, 16]. These effects were mostly caused by the time-varying stiffness' nonlinear properties, the fluctuating Hooke's joint's disturbance, and the mass imbalance of the rotor system. Numerous scholars have used the Cardan shaft analysis since Porter [17] to forecast the synchronous critical resonance range connected to such a coupled rotor system because of its compactness, noise, and high load capacity.

Instead of the driven shaft, which exhibits considerable vibration, these faulty events primarily affect the driveshaft [18]. The driveshaft becomes increasingly susceptible to periodic excitation owing to rotational speed as it is aligned with the motor, and Hooke's joint disturbance may further cause early failure. A sudden interruption of the power supply between its source and the consuming device may occur if such a system fails. Therefore, the investigation should be done to identify and foresee various defects that may result from the Cardan shaft's defectiveness mechanism.

II. SYSTEM DESCRIPTION

The current four-wheel-drive systems used in MR-based vehicles and those with close engine-to-axle spacing. The connection's increased strength, quality, and durability are all a result of the friction welding performed at the junction. It is used in a front engine, front drive, four-wheel-drive vehicles as well as vehicles with a large gap between the engine and the axles. The critical number of revolutions is lowered when the Cardan shaft is split into two or three sections, preventing vibration problems when the shaft's overall length is extended. However, the existing system has a few problems as stated in the present section [19, 20].

Several circumstances can lead to the failure of different driveline components. A Cardan shaft's many components may fail if enough of them do. Here is a list of words that characterize typical driveline failures [21]. Excessive torque load sometimes referred to as torsional fatigue, is a sustained force exerted on a driveline component that is greater than the specifications that are advised. Pulling a load that is heavier than the vehicle is designed to handle frequently results in excessive torque. When the installed driveline parts are not compatible with the vehicle's specifications or intended use, this is known as improper application. When a drive shaft operates at an RPM that is excessive for its length, diameter, and mass, this is known as critical speed [22].

To overcome the limitations of the existing system, the present study proposed an alternate system. Transmission shafts are a common component of both vehicles and locomotives. If it can be done without increasing costs or sacrificing quality and dependability, reducing the weight of the Cardan (drive) shaft can play a part in the overall weight reduction of the vehicle [23]. Using different stacking sequences, it is feasible to create a modified Cardan shaft with reduced weight, increase the shaft's natural frequency, and reduce bending stresses. The methodology of the currently proposed system is explained in the next section.

III. METHODOLOGY

Figure 1 demonstrates the flow of methodology of the present study. All steps are explained in the current section.

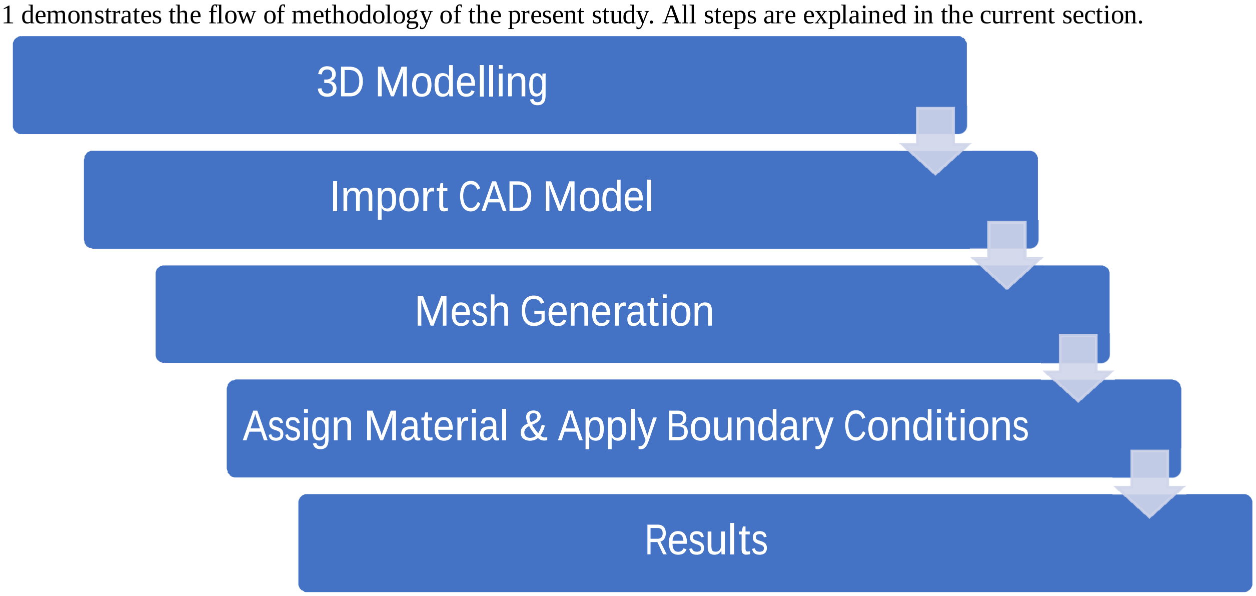

Figure 2: Flow of Methodology

Three various CAD models of Cardan shaft were created using SolidWorks software namely 1. Circular Cut (figure 3(a)), 2. Rectangular Cut (figure 3(b)), and 3. No-cut (figure 3(c)).

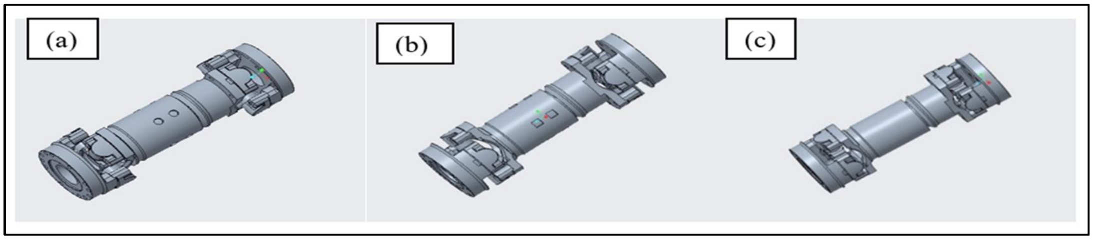

Figure 3: 3D Model of Cardan Shaft: (a) Circular Cut, (b) Rectangular Cut, and (c) No-cut

Furthermore, in order to perform the Finite Element Analysis, the CAD models were imported into the ANSYS software. The numerical mathematical technique known as the Finite Element Method, or FEM, is known as Finite Element Analysis, or FEA, and it is used to simulate physical phenomena. Many different fields, including mechanical engineering, rely on this procedure. It serves as one of the fundamental tenets for creating simulation software. Engineers can use this FEM to reduce the number of physical prototypes required and conduct virtual experiments to enhance their concepts [24].

With ANSYS structural analysis software, users can take on challenging structural engineering difficulties and make better, quicker design decisions. The FEA solvers in the suite allow you to parameterize them to analyze various design scenarios while customizing and automating solutions for your structural mechanic's challenges. For even greater accuracy, you can also quickly connect to other physics analysis tools. Engineers from all over the world use ANSYS structural analysis software to enhance their product designs and reduce the costs associated with physical testing [25].

Mesh generation is the initial step to perform FEA structural analysis after importing the CAD models in ANSYS. One of the most crucial processes in carrying out an accurate simulation using FEA is meshing. A mesh is composed of elements that have nodes—coordinate positions in space that might change depending on the element type—that symbolize the geometry's shape. Uneven forms are difficult for an FEA solver to work with, but typical shapes like cubes make it much happier. Meshing is the process of transforming amorphous shapes into "elements," which are more discernible volumes [25].

Mild steel is a form of carbon steel with very little carbon, also referred to as "low carbon steel." Mild steel normally contains 0.05 to 0.25 percent carbon by weight, whereas heavier carbon steels are typically said to include 0.30 to 2.0 percent carbon, depending on the source. Steel would be classified as cast iron if any more carbon were added to it [26]. The models' boundary conditions were then applied, allowing the modal analysis to be performed for various cut geometries and the modes of natural frequency analysis on Cardan shafts to be determined. The results of the analysis are explained in the subsequent section.

IV. RESULT

The modes of natural frequency analysis on the Cardan shaft can be concluded using the modal analysis for various cut geometries. In this analysis, the various cut geometry forms are determined by the highest frequencies. Following model analysis, all modes are summarized according to their deformation and natural frequencies. Table 1 lists the deformation (mm) and natural frequency (Hz) for six different modes for circular cut, rectangular cut, and no-cut CAD models. Figures 4 and 5 compare all the CAD geometries for deformation and natural frequency, including circular cut, rectangular cut, and no-cut.

Table 1: Deformation and Natural Frequency

Modes	Circular Cut		Rectangular Cut		No-cut	
	Deformation (mm)	Frequency (Hz)	Deformation (mm)	Frequency (Hz)	Deformation (mm)	Frequency (Hz)
1	5.08	0.00	5.02	0.00	5.11	0.00
2	15.32	543.42	15.20	542.01	15.54	560.55
3	15.77	589.25	15.63	588.99	15.97	602.63
4	6.89	926.14	6.78	924.22	7.01	1199.23
5	6.03	998.86	5.98	997.22	6.12	1198.56
6	7.44	1005.66	7.21	1004.69	7.69	1523.33

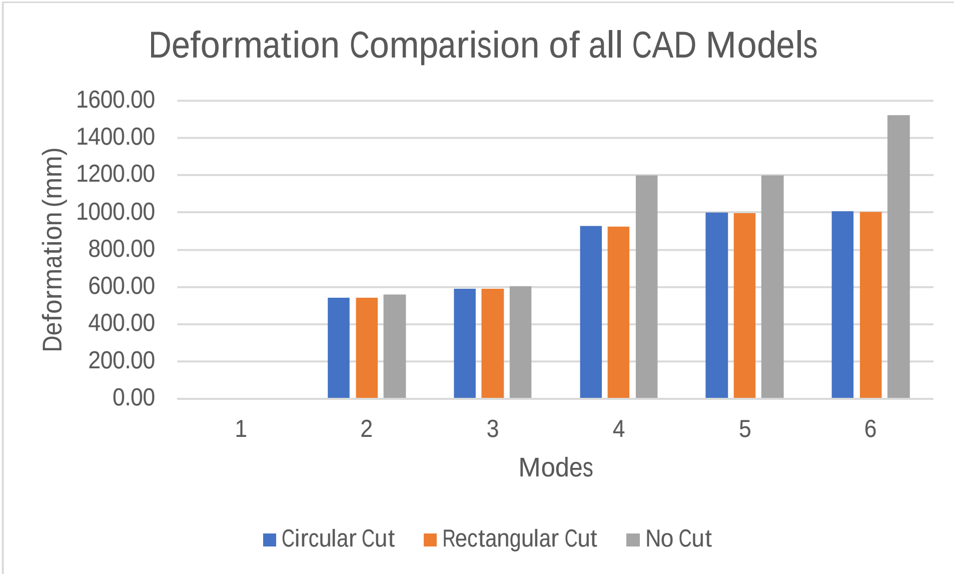

Figure 4: Deformation Comparison of all the CAD Models

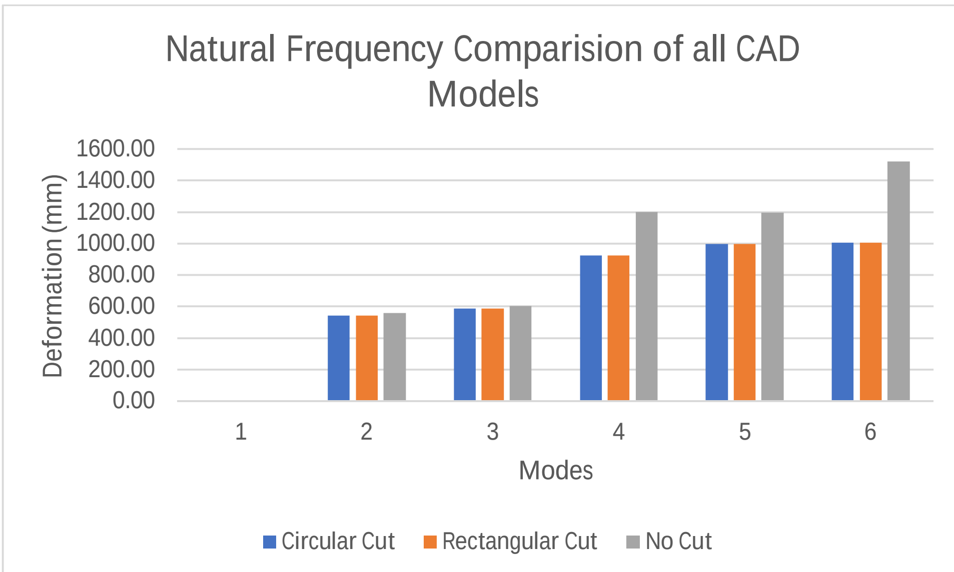

Figure 5: Natural Frequency Comparison of all the CAD Models

V. CONCLUSION

The authors of the article draw the following conclusions after doing a modal analysis of three different geometries, namely circular cut, rectangular cut, and no-cut, for six modes:

1) For all six modes, the rectangular cut geometry of the Cardan shaft generated the least amount of deformation. On the other hand, the Cardan shaft's no-cut geometry produced the most deformation.
2) Using the rectangular cut geometry of the Cardan shaft, the lowest natural frequency was also achieved. However, the Cardan shaft's no-cut shape produced the highest natural frequency.
3) As a result, among all the CAD models, the rectangular cut shape of the Cardan shaft is superior. Furthermore, compared to no-cut geometry, the circular cut geometry exhibits better outcomes.

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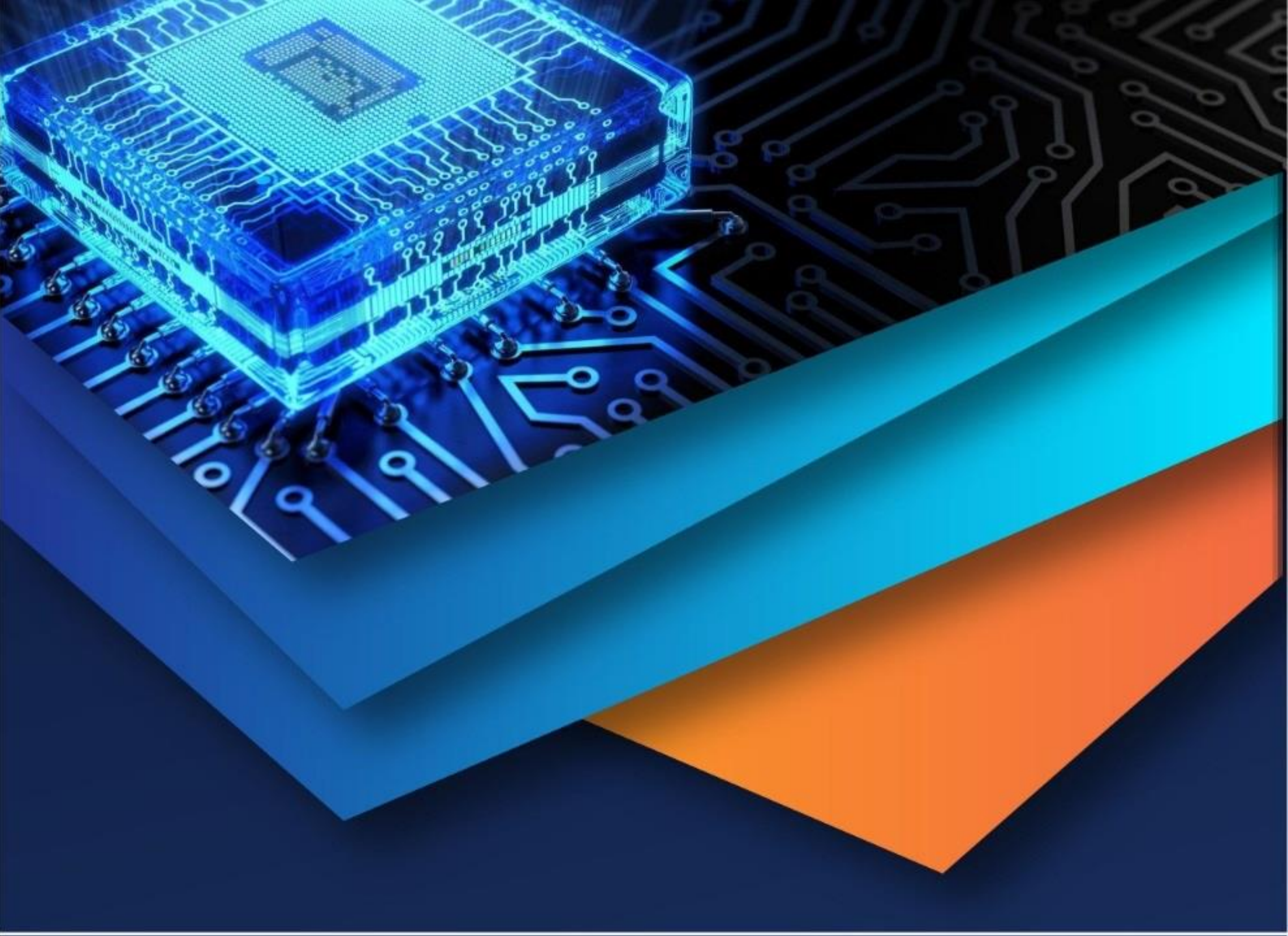

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