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CASE STUDIES IN MACHINE DESIGN THEORY[2]

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Abstract: *The paper reviews approaches in theory of machine design. The objective of the research is to evaluate and to compare the relevance of different methods elaborating complex, original and creative design tasks. The authors analyze the interactive models of communication between lecturers and students and the group dynamics of teamwork during the implementation of creative design case studies. The authors' team shows results of the applied theoretical methods in selecting appropriate procedures for calculation and design of mechanical components and units. Conclusions are made concerning the importance and the application options of machine design theory.*

Keywords: *Case Studies, Machine Design Theory, Interactive models, Group Dynamics, Mechanical units.*

INTRODUCTION

The classic learning and teaching methods of scientific study material consisting of theoretical knowledge, empirical relationships and formulas often turn to be a challenge for solving creative, non-standard problems in the field of design theory. These methods usually lead to limiting the creative thinking of students. The results are design assignments developed according to a preliminary given (by the lecturer) sequence of steps for solving the task. Sometimes this sequence is almost in the form of a prescription for solving the assignment.

Finding solutions for such complicated problems both from pedagogical and from methodological points of view is a real challenge for the academic staff responsible for the study process and for the independent scientific work of students. This dynamic situation imposes changes in the teaching and lecturing methods applying new and modern technological solutions stimulated by the development of design and information technologies.

In order to investigate the research methods for finding solutions of creative case studies it is necessary to analyze, compare and evaluate some important scientific achievements of renowned scientists working in this area. The machine design theory aims to explain explicitly the procedure for creating new technical products. Some of the well-known scientists who have analyzed the features of engineering design from different points of view are are: Pahl and Beitz (Pahl, G., Beitz, W., Feldhusen, J. & Grote, K. H., 2007), Pugh (Pugh, S., 1990), Roozenburgh and Eekels (Roozenburg, N. F. M. & Eekels, J., 1995), Collins, Busby & Staab (Collins, J., Busby, H. & Staab, G., 2009).

The objective aim of the paper is to present important specific features of the applied aspects of the design theory for solving creative and complex case studies.

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CASE STUDY IN DRIVING SYSTEMS

There are different classifications for the stages of machine design of a new product (from 4 up to 9). The stages of design activity proposed in (Collins, J., Busby, H. & Staab, G., 2009) are: include preliminary design, intermediate design, detail design, and development and field service.

(1) Preliminary design is primarily concerned with synthesis, evaluation, and comparison of proposed machine or system concepts. The result of the preliminary design stage is the proposal of a successful concept to be designed to meet specific criteria of performance, life, weight, cost, safety, or other aspects of the overall project.

(2) Intermediate design embodies the spectrum of engineering design of individual components and subsystems for the already pre-selected machine or system. The result of the intermediate design stage is the establishment of all critical specifications relating to function, manufacturing, inspection, maintenance, and safety.

(3) Detail design is concerned mainly with configuration, arrangement, form, dimensional compatibility and completeness, fits and tolerances, meeting specifications, joints, attachment and retention details, fabrication methods, assembly approach, maintainability, safety, and establishing bills of material and purchased parts. The result of the detail design stage is a complete set of working drawings and specifications, approved for production of a prototype machine.

(4) Development and field service activities include development of a prototype into a production model, and following the product into the field, maintaining and analyzing records of failure, maintenance procedures, safety problems, or other performance problems.

The authors' team studied some successfully completed case studies in the field of machine design theory at the University of Ruse and the design stages described in these investigations.

The creating of a new technical product is usually preceded by intensive theoretical research. Similar exemplary and successful investigations are presented in (Dobreva, A., 2013) and (Dobreva, A. & Stoyanov, S., 2012). Studies corresponding to the second stage of the design process and related to the creation of software products for data processing and visualization of results, are described in (Kamenov, K., Dobreva, A. & Ronkova, V., 2017), (Dobreva, A. & Dobrev, V., 2018), (Stoyanov, S., Dobrev, V. & Dobreva, A., 2017) and (Dimitrov Y. & Kamenov K., 2019).

One of these products is a test machine for experimental research of energy efficiency in mechanical gear trains and reducers, described in details in the following publications: (Dobrev, V., Dimitrov, Y., Dobreva, A., Kamenov, K. & Ronkova, V., 2016), (Dobrev, V., Stoyanov, S. & Dobreva, A., 2015), (Dobreva, A., 2013), (Dobreva, A. & Dobrev, V., 1993) and (Orzech, K., Khoshaba, S. & Dobreva, A., 2009).

Based upon the preliminary investigation done, a case study about a vehicle as an example of an engineering system has been implemented. It starts with a list of the failure modes which might be significant, and the locations where each failure mode might be active.

Table 1 shows some results of these investigations.

Table 1. Failure Modes and locations in a vehicle

№	Possible Failure Mode	Possible Location
1	High-cycle fatigue	Shafts, gears, springs, belts
2	Impact fatigue	Shock absorbers
3	Surface fatigue	Bearings, gears
4	Corrosion fatigue	Springs, driveshaft
5	Adhesive wear	Bearings, gears, brakes
6	Corrosion wear	Brakes, suspension components
7	Buckling	Body panels, springs

The second stage of the creative case study includes an appropriate design of a drive shaft from a snowmobile, Fig 1. The drive shaft is chain-driven by sprocket. The maximum engine output is 20 kW at a vehicle speed of 72 km/h. Because the track and chain do not impose stringent deflection requirements and the bearings could be self-aligning if necessary, the preliminary design should be based on fatigue strength.

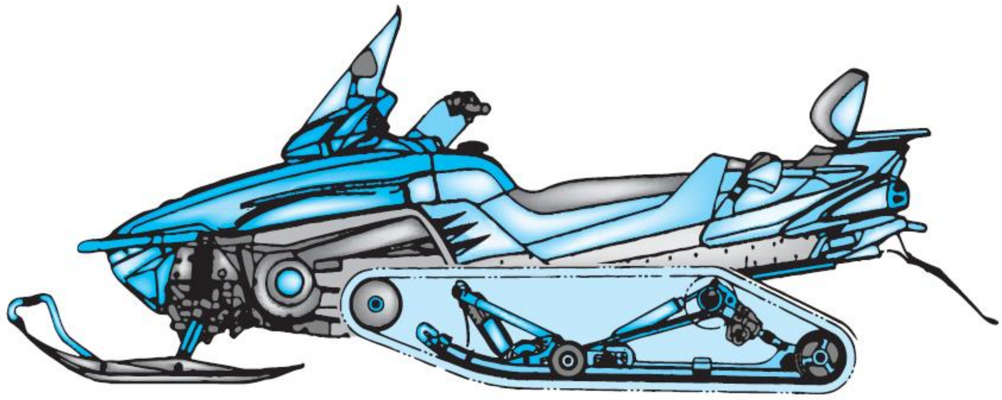


Fig. 1. Snowmobile, (Juvinall, R. & Marshek, K., 2012)

The authors' team set the following design procedures and assumptions within the second stage of the design process: the chain sprocket is to be mounted in such a way, so that easy access to the chain for servicing is provided; one of the bearings is to be calculated to carry thrust load in both directions; the torque will be transmitted from the chain sprocket by splines and to the track sprockets by keys; based upon cost considerations, appropriate cold-drawn steel is to be selected.

A safety factor of 2.5 is chosen based upon literature sources; force, shear, and moment diagrams for the vertical and horizontal planes are to be determined; applied horizontal loads include the chain tension component and the track sprocket forces; following the procedure specified for general biaxial loads the equivalent alternating stress is due only to bending and the equivalent mean stress is due only to torsion; a fatigue strength diagram is to be drawn for checking the appropriate selection of the shaft material; the angular deflections should be calculated in order to determine whether self-aligning bearings are necessary.

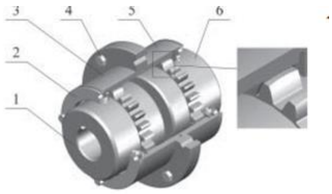
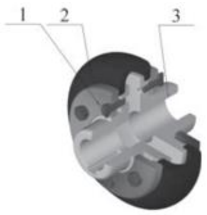
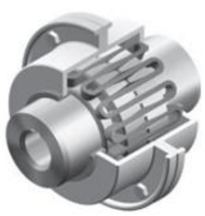
CASE STUDY IN SELECTION PROCEDURES

The second creative task is to select an appropriate flexible coupling, which has to connect a worm gear reducer with a coal conveyor inclined at 12°. The output torque of the reducer is T = 395 Nm, the speed of the output shaft is 42 min^{-1}. The gear ratio of the reducer is 30.

Different types of flexible couplings have been analyzed, described in (Dobreva, A. & Dobrev, V., 2007), (Stoyanov, S., Dobrev, V. & Dobreva, A., 2019) and (Jiang, W., 2019).

Based upon the theoretical study implemented, the authors composed a matrix aiming to support the selection of a suitable flexible coupling for the practical case pointed out.

Table 2. Selection Matrix for Flexible Couplings

№	**Types of Couplings, (Jiang, W., 2019)**	**Parallel offset**	**End float**	**Angular misalignment**	**Shock absorption**	**Features & Applications**
1. Gear Coupling		Yes	Yes	Yes	No	Small radial size; large power transmission capacity; Suitable for frequent start/stop cycles, high-speed and heavy-duty applications.
2. Chain coupling		Yes	Yes	Yes	No	Simple structure, compact size, convenient for maintenance; Suitable for hostile environments, (high-temperature, humid & dusty conditions)
3. Tyre coupling		Yes	Yes	Yes	Yes	Simple structure, excellent misalignment compensation & vibration dampening capability, yet require ample radial space; Suitable for frequent start/stop cycles, reversing torque loads, heavy shock, vibration applications.
4. Metallic grid coupling		Yes	Yes	Yes	Yes	Good misalignment compensation capability, complicated structure, require lubrication; Suitable for shock loading, medium to high power transmission

Analyzing the possible 4 flexible couplings, their misalignment and shock absorption capabilities, special features and application, the following two couplings will be selected: Gear or Tyre coupling. The final version will be chosen after discussions with the assignor enterprise.

CONCLUSIONS

The study presented allows to draw the following conclusions:

Solving creative, non-routine casse studies requires prior independent research work implemented by students.

The lecturers consulting students for developing such creative tasks need considerable time to work individually with these students.

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