An Algorithm to Simplify and Formulate Assumption in Gear Box Design Analysis

Nur Maisarah Bt Shahril Khuzairi, Manjit Singh Sidhu

College of Information Technology, Dept. of Graphics & Multimedia Universiti Tenaga Nasional (UNITEN), Kajang, Selangor, Malaysia

Abstract: The ability in making assumption or estimation among mechanical engineers is essential, because in real life situations, engineers are required to make assumptions based on the incomplete data provided. However, engineering undergraduates are found to have problem in making assumptions even with all the data provided in the question. Without such skill set, undergraduates are at risk in applying their knowledge to the working domain upon graduation. Hence the purpose of this paper is to discuss on an algorithm that formulates a systematic approach for students in making assumptions to solve problems on gear box design. This approach can help students in understanding the subject matter better and formulate assumptions intelligently based on the data given, instead of creating blind guesses in solving problems, specifically in the subject of gear box design.

Key words: Engineering; education; algorithm; problem; gear box.

INTRODUCTION

Engineering courses are known for their numerous formulas, parameters, tables and graphs. Undergraduate students are required to connect formulas from different Chapters to create connection between the topics and to see a larger picture of the information they have learnt. However, this arises questions on the student’s ability in making assumption based on their engineering knowledge learnt. For instance, after attending a series of lectures conducted on spur gear design, students are expected to have the ability in making assumptions based on their understanding on the subject matter to solve the problems related to spur gear design, even when the questions are ill-structured or incomplete data is provided in the question. With all the formulas, theories and examples given in the lectures, still there are students that have a problem in making assumptions and explaining the assumptions they have made accordingly. Students who are incompetent in making assumptions would then refer to other’s solution without understanding the assumptions that are being made.

Such a skill set is difficult to acquire as it requires a thorough and complete understanding of the subject matter to be able to make assumptions. At present, the steps designed in the mechanical engineering textbook guides undergraduates in solving the problem without providing enough time for students to make assumption or explaining on the assumptions made in the problem solving it. This could potentially discourage students in learning and would bring them into a false sense of complacency with regard to their actual understanding of the topic when being tested by a real-world problem. Hence this research work presents an algorithm that solves problems related to gear box design calculations and helps students in formulating assumptions accordingly.

This paper is structured as follows: Section 1 presents a background review that is correlated with non-specific references on the implementation of algorithm in computer software or other field of studies, this is due to the limited references of the implementation of algorithm in the spur gear design. Section 2 proposes the design of an algorithm for gear box analysis. Section 3 provides an example of use of the algorithm and improved algorithm that promotes students ability in making assumptions. Additionally explains in details of the implementation of the algorithm by providing an example of use in problem solving. Finally the last Section provides a conclusion and further works to the research.

Background Review:

A. Introduction of Algorithm:

In computer science, algorithm is the logic written in software by software developers to perform a specific procedure or function from a given input (Smith, 1985; HowStuffWorks, 2013). It is also known as a well-defined step-by-step procedure for calculation, data processing, and automated reasoning that starts from the initial input data provided by the user or pre-defined by the programmer. The input data will then be executed by the step-by-step procedure that will provide a result upon completion of the procedure, which is known as the output.

Algorithm can be illustrated in a different kind of notations such as flowcharts, pseudocode, control tables and programming languages (Hanly and Koffman, 2007). These algorithm notations are then verified by testing it with the actual problem before implementing it into software. Besides the representation of algorithm in such way eliminate ambiguities and promote better understanding among other programmers too.

Corresponding Author: Nur Maisarah Bt Shahril Khuzairi, College of Information Technology, Dept. of Graphics & Multimedia Universiti Tenaga Nasional (UNITEN), Kajang, Selangor, Malaysia.
E-mail: my.sarah1990@gmail.com

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B. Implementation of Algorithm:

Over the years, many algorithms have been developed and implemented in various fields to perform a certain function or calculation, such as the deterministic algorithm, genetic algorithm, divide and conquer algorithm, dynamic programming algorithm, linear programming algorithm and many more. Among all the algorithms mentioned here, two algorithms that have been widely implemented and adopted will be discussed in the next section, which is the deterministic algorithm, and divide and conquer algorithm.

1) Deterministic Algorithm:

Deterministic algorithm has been broadly employed to various fields such as communication (Malekpour et al., 2008), computer science (Chen et al., 2011; Matousek and Schwarzkopf, 1996), engineering (Chen et al., 2011; Errico et al., 2007) and neurocomputing (de Angulo and Torras, 2002), because it is one of the most practical approach that is feasible in a computer. Besides, this algorithm has a behavior that is deterministic or predictable (Black, 2009), which allows user to obtain the same output at all time. It will start from the initial state with the input data provided by the user and then it determines what the next step will be by processing the input data through the predetermined set of rules until it reaches the end.

One of the common examples that use the deterministic algorithm is the pseudo-random number generator. Pseudo-random number generator is to be known as a function that create a series of random numbers (known as a stream) (developerWorks, 2000), but the truth is that the random numbers generated are based on a predefined formula by the programmer. In the random number generator algorithm, as long as the initial number is given and it will pass though the function and the next number can be efficiently calculated and predicted (William et al., 2012) if one can identify the pattern of the algorithm. Hence deterministic algorithm in generating random number is still an active area of research.

However, predictable results by the deterministic algorithm have also been applied in other area of research like neurocomputing. The deterministic algorithm is used to minimize the predicted error of a feed forward network of random weights and the results produced turned out to have very high in precision level (de Angulo and Torras, 2002), as the deterministic algorithm produces the same output at all time. Such high precision level would be helpful for engineering undergraduate students in problem solving so that a consistent result can be produced time after time.

2) Divide And Conquer Algorithm:

According to the study by Smith (1985), the principle of divide and conquer algorithm can be as simple as breaking down a problem that cannot be solved directly into sub problems to be solved independently, then by combining the sub problem’s solutions to compose the solution to the original problem. This algorithm attempts to make a complicated and difficult problem into smaller manageable problems, then solve the smaller problems individually, and lastly reassembling the original problem with the solutions from the simple problems. So it can be understood and solved using a simpler approach instead of spending longer hours to work out the complex problem by itself.

The reason that divides and conquer algorithm is favorable in problem solving because it has a structural simplicity which promote understanding, computational efficiency, parallel implementation and the diversity of applications (Smith, 1985). With such characteristic of the algorithm, it has also been used for problem solving and learning, which has shown to have a faster and higher quality result based on the study by (Stach et al., 2010; Arbenz, 1992).

Methodology, Proposal and Design of an Algorithm for Gear Box Analysis:

Hence in this paper, deterministic algorithm and divide and conquer will be employed to solve the problem suggested. This is because the deterministic algorithm provides time for students to make assumption based on their input rather than having the computer to do all the calculation and as for the divide and conquer approach allows students to break down the complicated questions into sub problems to be solved easily.

The flowchart shown in Figure 1 depicts the 9 steps proposed algorithm in computing the bending stress for gear and pinion. The algorithm begins with the state of students obtaining data provided in the question such as what are the given values and remaining values to be resolved. After obtaining the data, students are to determine the machine or application that this pair of gear will be used on so that the assumptions can be made accordingly. In the 3rd state, the divide and conquer algorithm has been applied to break down the parameters obtained from the questions to either constant or non-constant. If it’s a constant parameter then the value will be put into the bending stress formula, whereas the non-constant parameters will be further broken down into the factors that contribute to the parameters (this is shown later in the paper). With all the data in hand, assumptions are to be made based on the criteria predefined by the AGMA (American Gear Manufacturers Association) standards. Then all the values from each parameters are brought together to be inserted into the bending stress formula to compute the value of gear and pinion bending stress.
Fig. 1: Proposed algorithm flowchart for solving problem on gear box design.

Example of use with Data:
In order to perform the algorithm assessment, the algorithm was applied to an example from the Machine Design book (Norton, 1998).

Problem:
Determine a suitable face width and the bending stresses in the gear teeth of the 3-gear train containing a pinion, an idler gear, and a gear. The transmitted load on the teeth is 432 lb. The pinion has 14 teeth, a 25° pressure angle, and $P_d = 6$. The idler has 17 teeth and the gear 49 teeth. Pinion speed is 2500 rpm.

The formula (1) for tooth-bending stress equation is as following:

$$\sigma_b = \left\{ \frac{W_t P_d}{(F J)} \right\} \frac{(K_a K_m)}{K_v} K_s K_B K_I$$

Where:
- $\sigma_b$: Bending Stress
- $W_t$: Tangential Force on the Tooth
- $P_d$: Diametral Pitch
- $F$: Face Width
- $J$: Bending Geometry Factor
- $K_a$: Application Factor
- $K_m$: Load Distribution Factor
- $K_v$: Dynamic Factor
- $K_s$: Size Factor
- $K_B$: Rim Thickness Factor
- $K_I$: Idler Factor

State 1: Obtain Data From Question:
Transmitted load, $W_t = 432$ lb; Number of Teeth - Pinion, $N_p = 14$; Idler, $N_i = 17$; Gear, $N_g = 49$; Gear Pressure Angle $= 25^\circ$; Diametral Pitch, $P_d = 6$; Pinion Speed, $\omega_p = 2500$ rpm.

State 2: Determine what Application is to be Developed:
Application: 3 gear train
State 3 and 4: Divide Each Parameter Individually Whether it’s a Constant:

According to the formula, \( W_t, P_d \) values are provided in the question so it can be categorized as constant. Whereas \( F, I, K_a, K_m, K_v, K_s, K_B, K_I \) values are not provided.

State 5: Determine Factors that Contribute to Each Non-Constant Parameter:

In each parameter, they have their own factors that contribute to the value of the parameter. 

\( F \) value is affected by \( P_d \), with the given formula of \( 8/P_d < F < 16/P_d \).

\( J \) value is affected by the number of pinion, idler and gear teeth, pressure angle, teeth profile with loading type, which is not given by the question, so the value will be assumed in state 6.

\( K_a \) value can be selected from a predefined table, but students have to make assumption accordingly to determine which is the best option.

\( K_m \) value is determined by a set of rules related to the value \( F \).

\( K_v \) value is computed by a formula of \( K_v = (A/(A+\sqrt{V_t}))^B \), but value of \( Q_v \) has to be determined beforehand because it is needed to compute value \( B \) in the \( K_v \) formula.

\( K_s, K_B, K_I \) values will be determined in state 6.

State 6: Make Assumptions According to the Data Provided:

\( F \) value is given in the range of 1.33 <\( F < 2.67 \), students can select any face width value from the given range.

If students are unsure with it, the face width value can be calculated by an average value of 1.33 and 2.67.

In order to make assumption on the teeth profile, students are required to answer a set of questions to decide whether it’s a 25% long addendum teeth or full-depth teeth profile. Questions are as follows:

Q1: Is a long addendum gear teeth required for the design?
Q2: Is the teeth working depth equals 2.000 divided by the normal diametral pitch?

If the answer to Q1 above is “yes” then the teeth profile can be assumed as 25% long addendum teeth, while the answer “yes” to Q2 will select the full-depth teeth profile.

The gear loading type for \( J \), can be decided by the value of \( Q_v \) and another set of questions can be used to assume the value of \( Q_v \). Students only have to answer either one or more questions based on the amount of data given in the question as a guideline in selecting the loading type.

Q1: What is the manufacturing method in creating the gear set? By roughing method, or finished by shaving or grinding or lapping and honing?
Q2: What is the pitch-line velocity?
Q3: Is \( Q_v \) > 6?

Based on a certain manufacturing method or pitch-line velocity, the gear quality can be grouped into a certain range of \( Q_v \). Once the \( Q_v \) has been determined, Q3 can be answered and if the answer to it is “yes” then the gear loading type is to be categorized as Highest Point of Single Tooth Contact (HPSTC) loading which is one with higher gear quality.

\( K_a \) is an application factor that determined by the amount of shock needed for the machine. A Table by AGMA has suggested values for \( K_a \) based on the assumed level of shock loading in driving and driven machine, so students only need to decide on the shock loading level for the application whether it needs a uniform, light, medium or heavy shock for the driving and driven machine.

\( K_m \) value is determined based on the face width, \( F \) by the load distribution factor table by AGMA.

Based on the value \( Q_v \) obtained from the earlier assumption, it can be used to calculate \( K_v \) with the predefined formula.

At the undergraduate level, \( K_S, K_B, K_I \) are all assumed as a constant of 1.

State 7: Compute all Non-Constant Parameters:

\( F = 2\text{in}; J \)’s pressure angle (25°), full-depth teeth with HSPTC loading with \( N_p = 14, N_i = 17 \) and \( N_g = 49; K_a = 1 \) with uniform shock for the 3 gear train; \( K_m = 1.6 \) based on the value of \( F; K_v = 0.66 \) with \( Q_v = 6; K_s, K_B, K_I = 1 \), except for the idler which will have a value of 1.42 for \( K_I \).

State 8 and 9: Put the Values into the Bending Stress Formula and Compute Bending Stress for Gear, Idler and Pinion by Referring to Formula (1):

In this calculation, it will refer to the bending geometry factor \( J \) table with 25°, full-depth teeth with HSPTC loading as following:

\( \text{Pinion, } \sigma_b = ((432)(6))/((2)(0.33)) \cdot ((1)(1.6))/0.66 \cdot (1)(1)(1) = 9526 \text{psi}; \)

\( \text{Idler, } \sigma_b = ((432)(6))/((2)(0.36)) \cdot ((1)(1.6))/0.66 \cdot (1)(1)(1.42) = 12400 \text{psi}; \)

\( \text{Gear, } \sigma_b = ((432)(6))/((2)(0.46)) \cdot ((1)(1.6))/0.66 \cdot (1)(1)(1) = 6834 \text{psi}. \)
Conclusion:
The ability in making assumption is rather essential for engineering graduates in solving real-life problems but still there are graduates who face problems in making assumptions upon graduation. Hence this paper has correlated some commonly discussed algorithms in the literature that have been implemented into other field of studies which can be very helpful in guiding students in formulating assumptions for problem solving like the deterministic and divide and conquer algorithm. With such promising result from the past studies, a combination of deterministic algorithm and divide and conquer algorithm strategy has been employed in helping students to make assumption for problem solving. The proposed approach also serves as an example to provide a simpler and understandable platform which could motivate students in learning the skill of making assumption, so that engineering graduates are academically and technically competent.

Further Work:
The algorithm can be further programmed (using a programming language) to act as a tutorial aid for students to promote the ability in formulating assumption with a guided algorithm. Besides, the feature of artificial intelligence could be included during the assumption making process, providing user some suggestions in making assumptions based on the data provided by the question.

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