Fuzzy Logic as a Tool to Compare Reliability of Torsion Bar System

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Abstract: One of most critical system in military vehicles is the suspension system and the reliability of the system is essential to maintain a mission capable status. When changes to the vehicle suspension system are warranted, the reliability of the system must be reevaluated to assure that service life is maintained. As the design to implementation cycles continue to be reduce, new tools are needed to be developed to aid in the decision making process. The purpose of the paper is to demonstrate the use of fuzzy logic programming in the prediction of reliability early in the design process.

In order to achieve this goal, this paper will evaluate a simple torsion bar system /road arm system to demonstrate the use of Fuzzy logic. By combining known failure issues on various systems, we will demonstrate the capability of the fuzzy logic program and how it will aid in making design decision to improve the overall performance of the system.

I. Introduction:

Today's Army is faced with an ever increasing amount of resources vying for the limited number of dollars in an already shrinking budget. Much of that budget is spent on maintenance over the life of the vehicle. Improving the durability of subcomponents or designing common component over several different vehicles should reduce maintenance cost. Both efforts have obstacles to overcome, as the engineering community is resistant to any changes that might have the unintended consequence of degrading the system in unintended ways. To overcome these obstacles the engineer needs to provide the evidence to the of the end user that changes are warranted, that the changes are cost effective and the reliability of the system will not be compromise.

Computer modeling is becoming more critical in the decision making than ever due to reduced cycle time and the perception that the data is accurate. The use of 3D modeling, FEA analysis and simulation models help to prove out ever-increasing complex systems, but these tend to be precise in their evaluation and do not speak to the reliability of the system. Especially in the beginning stages of design process as it is hard to predict the reliability of the system from a strictly analytical method.

This paper is proposing using fuzzy logic programming in a decision making role early in the design stage of the various systems. Fuzzy Logic Programming was developed for the electronic control systems where imprecise reasoning is used to make decision. Fuzzy Logic employs data that have various degrees of relationship and uses reasoning based process to make decision. Typical the uses of fuzzy logic are in microprocessors to implement control decision.

By apply fuzzy logic concepts to the early stages of a design effort, it is hoped to be able to develop new decision making tool to predict the future reliability of a product. Fuzzy logic allows imprecise data as opposed to precise or exact figures to be used in the decision making process. In this paper we will be looking at typical torsion bar suspension system design and the possible use of Fuzzy Logic software in looking at the effects on reliability.

II. Torsion bar Suspension system.

The torsion bar suspension system used in most armor tracked vehicles can be broken down to four main systems, each with their own reliability issues. These systems are as follows: Torsion bar and anchor, road arm assembly, road wheel and in some cases a damper of some sort. For the demonstration of this package the author chooses to concentrate on the torsion bar and road arm assembly as a major subsystem.

The torsion bar/road arm assembly supplies the torque necessary to position the road wheel and maintains appropriate vehicle height. In the

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static position, this force then positions the road arm assembly and sets the ride height of the vehicle. When the vehicle is in motion it absorbs some of the road forces which aids in the ride quality of the vehicle.

Torque is generated in the torsion bar when force is applied to the end of road arm via the road wheel and the weight of the vehicle. As the weight of the vehicle is increased and the dynamic forces caused by the vehicle traveling through uneven terrain, more torque must be generated. These forces are distributed through a variety of components and points throughout the system and induce stresses which can lead to material failure and thus reduce the reliability of the system.

Although there are many potential failure modes in the suspension system, this paper we will only demonstrate the method using the top two failure conditions. These two failure conditions are the result of the forces applied to the road arm and the torsion bar. The torsion bar, which is essentially acting as a wind up spring, may fatigue over time due to the cyclic loading of the bar over time. The road arm typical fails due to bearing failure which is caused by surface wear. These two failures is a significant cause for failure in the suspension system.

Durability of the torsion bar is dependent on the maximum stressed induced into the bar and the cyclic stress the bar sees in use over time. Stress is governed by the following equation:

$$\tau = ((G*\Theta) * R)/L$$

Where:

τ is stress
G is Modulus of Rigidity
Θ is Angle of twist
L is bar length
R is road arm radius.

In the case of the torsion bar you need to apply this equation to any preset condition applied to the torsion bar but also you need to apply look at the stresses do to cyclic load applied due to the system during operation. The combination of the load stress and the cyclic stresses generally causes failure to the torsion bar over time.

Typical failure mode of the road arm is due to the bearing interface between the road wheel and the road arm. In order to determine the proper load rating of a bushing, a Pressure-Velocity (PV) value is calculated and combined with various manufacturers' material information can calculate wear and life calculations. PV can be characterized by the following equations:

$$P = \frac{F_R}{D \times L}$$

Where P is the calculated pressure
F_R is the Radial Force
D is the diameter of the bearing
L is bearing length

And

$$V = \frac{\pi \times D \times N}{60 \times 10}$$

Where V is the velocity
D is the shaft Diameter
N is the shaft rotational speed in RPM

This number is then compared to the material ratings supplied from a bearing manufacturer to determine the suitable bearing.

III Reliability

Knowing the physics of the situation, we now turn our attention to the problem of predicting the reliability of the system with minimal information. Reliability is defined as the ability of system to perform and maintain its function in routine circumstances.[1] For the system proposed in this paper, it will be the ability of the suspension system to maintain a torque that achieves the appropriate ride height is what is deemed critical. All systems have a part

Reliability is measured as a function of the failure rate of the components during it desired life. Mathematically it is represented by the following,

$$R(t) = Pr\{T > t\} = \int_t^{\infty} f(x)\,dx,$$

where f(X) is the failure probability functions

[1] Wikipedia, the Free Encyclopedia

and t is the length of time[2]. This can be represented graphically by plotting system or component failures versus time and determining the slope of the line through curve fit software. A failure rate can then be calculated. Different probability density functions can be found in literature but the Wiebull or Exponential distributions are most commonly used.

Typically, failure rates are generally established on subcomponents first and then combined to provide an overall rate. This is because of lower test cost and the ability to isolate a particular product function. The numbers from the various subsystems are then mathematically combined to provide the overall reliability of the completed system.

To calculate the overall system reliability value you need to first make a block diagram of the system to determine which components act in serial or which act in parallel to form the overall system. In my simplified system we have two systems acting in serial. The road wheel is attached to the road arm which is attached to the torsion bar which is anchored to a fixed position in the vehicle.

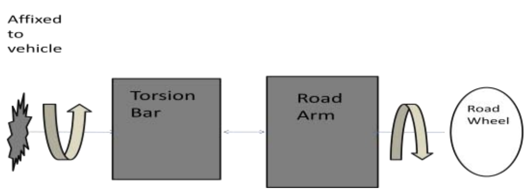

Fig. 1 Block diagram of torsion bar suspension system

Classical Reliability equations for components in series are equal to the product of their individual reliability.

$R_S (T) = \prod_{J=1}^{n} R_n (t) = R_1 (t)\ R2 (t) ... Rn (t)$

This requires obtaining actual test results for each of the subsystems and multiplying the numbers in series. As all reliability numbers are less than one, you can than see that the more components you have the lower the reliability number.

[2] Wikipedia, Reliability Engineering , Reliability Theory section

IV. Fuzzy Logic Proposal

Fuzzy logic is a method deriving an output through a set of reasoning logic applied to fuzzy set of data. Probabilistic membership functions are assigned to these fuzzy sets so that a set of rules can be applied to achieve the desired output. Examples of fuzzy sets are warm water, fast cars, overweight, etc where a statement is made but many different members may be a part of that set. These members are then assigned some degree of membership from zero to one through a membership function. (See Fig. 2). Classically you would have sharp cut offs and all the values would be equal. But in fuzzy logic probabilistic membership are assigned to the fuzzy set which then can be used with a set of rules written in more of a logic statement than mathematically. These rules take an "IF Then" type statement.

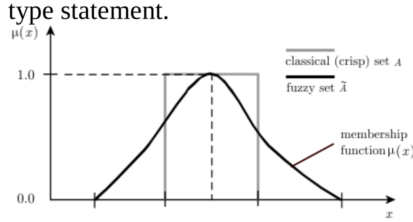

Fig. 2 Membership Function Example[3]

Fuzzy Logic was primary developed for the microprocessor controls to speed up the programming time on some applications. By taking applying the fuzzy sets and rules, you eliminate a lot of programming lines that classical controls would need to look at each condition possible. The Fuzzy sets would in affect tell the control to apply the rule depending on the conditions being read. But can this system be applied to non-electronics application and used a design tool to aid the decision making process.

A paper by Arati Dexit, Harpreet Singh and Kassem Saab presents a possible scenario of simulating reliability using Fuzzy Logic.[4] This paper transforms the component into various nodes to determine the finally reliability of the system. By defining the various nodes with assigned values, one might be able to simulate the reliability numbers prior to building the unit. This would allow designers to discuss

[3] Wiktionary : Fuzzy Set

component tradeoffs to determine possible size and cost of the components.

To demonstrate this, this paper is looking at the possibility of allowing the designer to look at the reliability numbers in terms of the force and stress calculations derived through classical methods. Most companies have old timers that will make claims that if we do this then the reliability of the system will be reduced. This is based on past experience of products already in production. By applying that wisdom and experience to some sort of model, then younger designer might be able to develop that same experience in a shorter time period.

To show this idea, a simple torsion bar suspension system will be analyzed in terms of forces and stress levels that may cause failures and are typical design issues with the system. Then these design characteristics will be used to predict the system reliability based on series of rules which are established by applying previous knowledge of the similar systems.

Two main subsystems, the torsion bar and the road arm, are associated with the torsion bar suspension system. Earlier in the paper we described the common attributes that a designer would typically work with in designing these particular subsystems. These attributes which can be calculated earlier in the design change process, can then be analyzed in terms of reliability, which could help predict the repair cost over the life of the vehicle.

For the torsion bar, stress is the prime characteristic that affects the durability of this particular subsystem. Generally, to increase the load capacity of the torsion bar the designer will preset the bar past the elastic limit of the part. This increases the load capacity of the part and allows the material to increase it stress level. Since the material is in an altered state, extensive testing has been conducted to determine the life of a torsion spring.

Material can be found in literature regarding the design stress levels of the torsion bar when acting as the spring member. For our example, let's take a torsion bar that is designed for 100000 cycles at 35K PSI minimum stress then we can predict the reliability based on those stress levels. So for demonstration purposes we will center our reliability statement on the values on the curve representing that condition.

If :

τ is between 20K and 30 K then R = High

τ is between 40K and 50 K then R = Nominal

τ is less than 50 K and 60K then R = Low

Reviewing the road arm typical failure is due to the bearing/bushing interface between the wheel and the road arm. Previous we described the characteristic is the Pressure-Velocity figure. Typically these numbers are expressed in parts catalog in short term and continuous operation. Typical value for steel bronze bushing is 3.6 N/mm^2 m/s for short term and 1.8 N/mm^2 m/s for continuous operations. By applying our reliability numbers within that boundary we should be able to define the following memberships:

If PV is from 4.2 N/mm^2 to 3.6 N/mm^2 then reliability is high, if PV is from 3,6 N/mm^2 to 2.6 N/mm^2 then reliability is Nominal and if PV is from 2.6 N/mm^2 to 1.8 N/mm^2 then reliability is Low

From the following figures show the above expression as presented to the software.

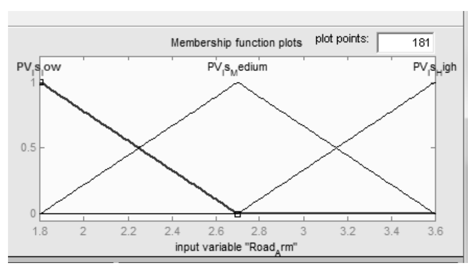

Fig. 3 Road Arm Membership function[4]

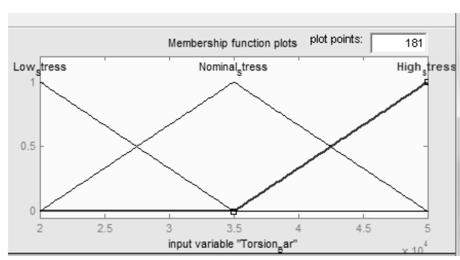

Fig. 4 Torsion Bar Membership Function[5]

[4] Simulation Software

[5] Simulation Software

The rules are then applied to the membership functions to obtain the desired output. Here we want to determine the reliability of the system based on the membership functions of the subcomponents. These rules are somewhat based on experience from the manufacturer of the components.

By applying fuzzy logic than we can form relationships between road arm and torsion bar in terms of the reliability. Special software using fuzzy logic will show the results in the form of a 3D map. In this incident we are proposing the following rules to apply:

Torsion stress is high and PV is high then Reliability is low
Torsion stress is nominal and PV is nominal then Reliability is medium
Torsion stress is low and PV is low then reliability is high

But to accomplish this we need to define reliability membership in terms that the Fuzzy Logic Software can make use in its analysis. Again this paper selects a triangle function to define Reliability. Reliability is a probabilistic number that is generally in mathematical terms between 0 and 1. For demonstration purposes we will use the entire range and not a partial range so that differentiation can occur. Once develop the engineer will need to review past data from his organization to determine the actual historical numbers that should be used in his company.

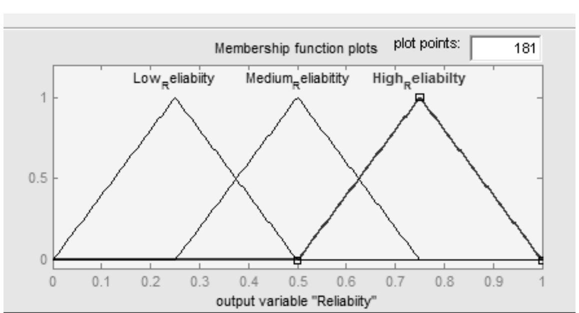

Fig. 5 Membership function of Reliability[6]

By applying the rules in and entering the membership in the appropriate software Packages, then a reliability map will be generated.

From this surface map design engineer can then compare tradeoffs of different bushing size and torsion bar sizes and base decision on reliability tradeoff. See Figure8.

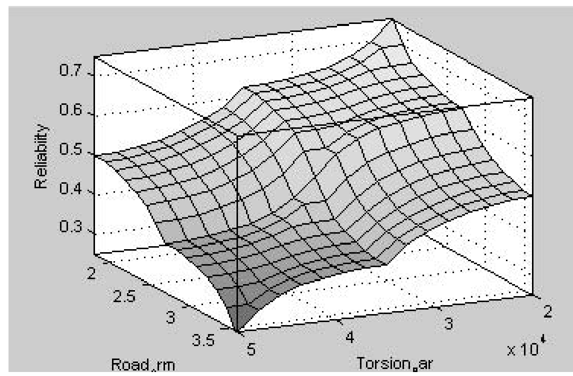

Fig. 6 Reliability Map: Torsion Bar Stress vs. Road Arm Bushing PV value vs. Reliability

Conclusion: This report demonstrated that may be possible to use Fuzzy Logic as in aid to the design process. By applying known force and stress levels and the relationship to reliability, we can design an appropriate algorithm that might help in the prediction of future reliability of the system.

[6] Simulation Software

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