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Significance of Nut Factor in Fastening of Joints in Engineering Structures

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Abstract: Threaded fasteners are category of bolts used in the joint assembling of aerospace structure. Torque is the process of applying a force that works at a circular distance and rotates the threaded fasteners at the bolted joints of these structures. With the aid of this torqueing force the two different parts are clamped together to form the joints. Due to torqueing there arises an opposing force which is known as the frictional force. The frictional force in threaded portion of the bolt transforms the applied Torque into stress. Due to this stress there is a chance of joint loosening or bolt fracture which is considered to be critical. Hence, selection of torqueing force for a desired preload is a major issue in joint deployment. The friction coefficient is a key factor for estimating the torque that is required for the fasteners to be deployed in the aerospace structures. There are many features which influence the friction coefficient for example size, pitch, thread tolerance. Till date only experimental methods and theoretical formulae has been used to estimate the friction coefficient, torque and preload. This paper identified the key features which are most correlated to coefficient of friction using the fisher score filtering technique and ca boost algorithm for both numerical and categorical datatypes. Along with that gives the insight on the torque, preload and coefficient of friction which are associated in fastening of the bolted joint in different non-permanent aerospace structures.

Keywords: Aerospace structure, coefficient of friction, fasteners, preload relation.

I. INTRODUCTION

The significance of torque in different field cannot be understated, in application such as aircraft structural joint installation or designing of the automotive engines or brakes or launch vehicle etc. Less amount of torqueing force can result in unnecessary loosening of nuts and bolts as well as structural joints where they are torqued. When the lesser amount torque force is applied it results in uneven preload. This uneven preload which is transferred all through the assembly structure may lead to joint failure. On the other hand, applying more torque force can be similarly destructive resulting in failure of a nut or bolt due to overloading.

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Torque required for specific joints in structure should be determined accurately and applied properly such that no joint failure occurs. The three major terminologies associated with torque are diameter of the bolt, friction and preload.

Most commonly there exist a misunderstanding in the relation of torque, preload and friction, when we try to tighten a threaded fastener to install a joint. This confusion has continued obviously for many years in mechanical joint installation. And, it leads to many research opportunities about fastener behavior during the installation of the mechanical joints and the torqueing mechanism.

The simplest equations that can define torqueing phenomenon behavior are precise, but the fallacy results give the wrong impression about their meaning. The most applied and frequently acknowledged equation for relating the various parameters of the torqueing mechanism is given by the equation 1.

$$T_1 = F\left[\frac{P}{2\pi} + \frac{\mu_T R_T}{cos\alpha} + \mu_B R_B\right] \quad [1]$$

Where, T_1 is torque applied to the fastener. F is the tensile force generated in the bolt as a result of tightening. P is the thread pitch. μT is the coefficient of friction between threaded portion of the fastener, R_T is the radius threads where the friction act. Cosα is the thread margin angle. μB is the coefficient of friction which occurs during the torqueing process between the threaded portion of the fastener and the contact surface, R_B is the length where the frictional force acts.

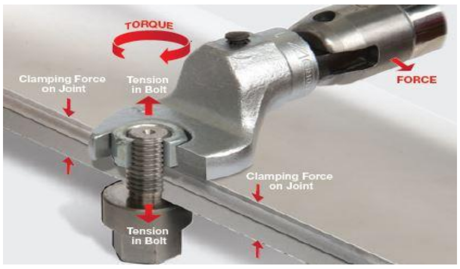

Fig 1 torque application in threaded fasteners

The above figure represents the various force applied acting on the threaded fasteners while applying torque for the installation of the joints.

II. LITERATURE REVIEW

Aerospace structures play a prime role in maintaining necessary external aerodynamic shapes while withstanding the flight loads and environmental factors. Most of the structures are held as joints with fasteners. Typically, fasteners which bear load have single point failure probability and hence internal control of these are of prime importance for joint success.

Fasteners used in aerospace structures are fabricated from high strength low steel. Application requirements demand these elements to stay in pre-loaded condition for months and in several environments at production and launch sites, to face up to temperature profiles and vacuum pressures. Such demands lead us to ensure quality of the fasteners right from the planning and analysis through material selection, product realization and testing.

Many computer science techniques have been used to make the study of the fastener state, some of them are as follows in Jeong et al. (2019), a study on the state of bolt fastening was made, where to get the structural vibration signal they used two types of sensor. Vibration signals where measured by application of indiscriminate initial movement at the unrestricted end of beam structure. Three different condition of fastened bolt where obtained based upon the variation in vibration signal namely fully torqued, half-torqued and 10% -torqued. Classification of the fastened bolt was done using k-nearest neighbor algorithm.

Y.-J.Cha, et al., (2016) has worked in a vision based identification of the loosened fastener where they have used haugh transform along with other image processing technique to identify the height and width of the fastener head and leave one out cross validation approach for the training the linear support vector machine which is considered to be operated in quasi real time application.

Baek1, et al., (2019) proposed finite element model for clamping and loosening evaluation. Three bolt size namely M12, M16, M18 was used for the evaluation. Simulating the torqueing process, the tension calculated was noted and compared with the numerical and experimental results, where they could calculate tension in the simulated joints with an error rate below three percentages. This three percentage error rate could be further reduced using machine learning algorithm and the computation cost also can be reduced.

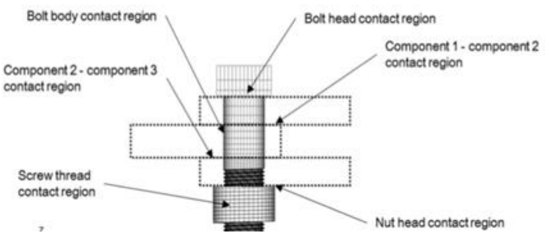

Fig 2 Illustration of contact region (Baek1, et al., 2019)

Dravid S et al. (2014) made a study to understand how much does the torqueing effect the loosening of the fasteners in mechanical joints which occurs in aerospace, railways, and other manufacturing industries. In this study an additional component named as washer was also considered to know the role of it on the success of the torqueing joint. An experimental setup was arranged where the fasteners where torqued with different values and different combination of washers. By this study there was a good understanding regarding the addition of washers in the fastening joints which help in life time of the joint and they could also determine the point at which the fastener starts to loosen and the speed it gets to loosen.

Meng e al., study was made on the problem of bolt fastening failure identification during bolt maintenance, where qualitative analysis of the mechanical mechanism of the track bolts was carried out, torque sensor was used to collect the data of the torque in different failure modes, three kinds of machine learning mathematical models, such as curve Euclidean distance, cluster analysis and regression statistical analysis, were established over the collected data. The failure forms of thread were analyzed one by one, and the analysis data was compared with the actual construction results. The experimental results which show that the discriminant analysis results of the machine learning mathematical model are consistent with the actual construction results, which proves the accuracy and feasibility of the model to judge the failure form of the sample data.

Deters et al., (2015), another bolt tightening study which was based upon the fuzzy logic controller system, here the process of tightening the bold was split into four stages, in stage one the bolt and nuts where aligned where the various factors such as the angle, position of the bolt and nut are to be considered. And on encountering the fault the system has to be stopped to realign or replace the bolt. In the stage two there is a partial engagement of the nut and bolt that is they are not fully fastened but touching each other. In stage two the possible error that can arise which was identified by the authors was one which can occur at the nut, second which can happen in the head portion of the bolt and third because of the various threaded pitch. These are the three major factors considered for the determination of the torque value to be applied in the joints. In the third stage the torqueing of the bolt and nut happens where the calculate the angular displacement to find the distance nut has been threaded which gives the length of the bolt. And in the final stage the keeping in consideration of the length of the bolt, the angular displacement of the nut, along with the preload of the nut and bolt the fastener torqueing is achieved. The author could achieve greater accuracy than normal controller which was previously used for the same purpose.

Althoefer K et al., (2008), in this study using artificial neural network the author has tries to classify the self- tapping threaded fasteners. Here the artificial neural network is trained to different simulated signals and then tested to the actually obtained torque-tension signals through experiment. By which the authors could achieve a new approach for detection of the failure of fasteners and classify them into their appropriate class. For this the authors have implemented radial basis neural network which examines the torque-tension signal obtained during the installation of the fasteners in joint.

III. AEROSPACE FASTENERS INSTALLATION

The fastening process is a confusing operation involving many data such as materials they are made, chemical or physical properties they possess, action or drive they undergo during installation, permanent deformation, operation on a machine and engineering, connection mechanism between two joints and others. Veiga et.al., (2019).

In emerging approaches for evaluating the state of joints in the engineering structure [Huynh et al., (2018), Jimenez et .al (2018)]., inspection for the evaluation of fastener installation is an essential component for overcoming the costs of aircraft construction, repair and service.

A. Modes of failure in bolts

At the interface of the nut and bolt at threaded end about 20 to 15 percentage and under the bolt heads, about 65 percent of bolt failures occur. Jadon et al., (1994) These are due to the nature of the bolts which have the stress raisers inherently. For example, when we're referring to Fig. 2 in order to increase the shock absorption potential of the bolt, the design must include a circular groove immediately after the threaded portion of the shank and should not exceed the diameter of the smallest thread diameter. If the concentration factor for fatigue stress is included in the design, then failure may be avoided. Ideally, the most suitable configuration of the bolt would have stress levels distributed equally across different cross section. Bhandari et al., (2010).

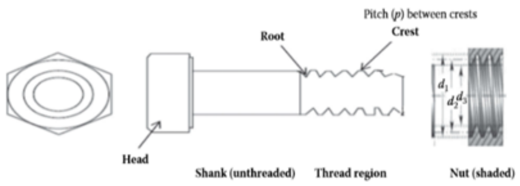

Fig 3 To depict the ideal condition for equal distribution of stress. Bhandari et al., (2010).

The various failure that can occur in bolted joints are namely, overloading(stretching), Fatigue, Shearing, Galvanic corrosion, Hydrogen embrittlement. Out of these stretching, fatigue and shearing occurs during the installation of the fasteners in the joint.

The factors mentioned early such as torque, preload, clamping force and coefficient of friction plays in the major role in the success or failure of the joints. These forces are determined till date by experimental method. And in recent times along with experimental method some of the machine learning methods are applied to know relationship among factors to avoid the fastener fatigue in the joints of the mechanical structures.

B. Preloading of bolts

After some free rotation, when the nut is closed or tightened, the bolt gets elongated and are held with stress, this stress is called the preload. In general, the fasteners in aircraft are regularly detected for loosen condition even though properly tightened. Very high stress will reduce the joint sustaining capability of the fasteners which will lead to loosening of joint and joint failure in working condition. Similarly, small preload will lead to allowance or cross movement in joints in the deployed load, which is very hazardous for the working of mechanical structures normally. Hence, preload has a major role in the joint success. QM Yu et al. (2018). The relation between the torque and the preload which is applied to combine two structures together are mainly affected by four factors namely clamping apparatus kit, bolt dimensionality, nut category and the plate category.

The simplest equation which describes the torque- tension and nut factor relationship is, T = F (k x d), where, T is the clamping force, F is the initial preload, d is the width of the bolt, k is the nut factor.

Most of the study conducted to study the relation of the three above stated factors or done by finite element methods. This numerical modelling method includes three stages. During the stage one a 3D modelling of the nut bolt assembly is achieved and various boundary condition or defined, in the stage two the condition is applied and during the stage three the result is analyzed, which is obtained during processing of the model. Then the obtained preload is compared with the experimental preload. [Jamadar et.al.(2016)].

C. The influence of lubrication and roughness on nut factor

Zou Q., et al., (2007) this works gives a brief relation of the effect of the lubricants in the torque preload and the nut factor. They were able to conclude that there exists an important role of the lubricant in the torque, preload and nut factor associated in the threaded fasteners. Here, they tried to conduct an experiment with three different lubricants and different torqueing force, calculated the coefficient of friction.

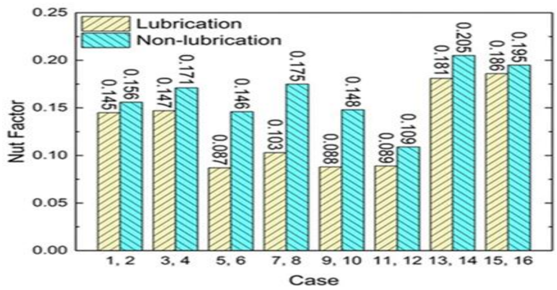

Fig 4 The impact of lubrication on torque- friction relation. QM Yu et. Al. (2018)

Fig 4 gives a graphical illustration of the consequence of lubrication condition on nut factor is realized by affecting the friction coefficient of connecting sides between bolt and nut. When the contact surfaces are lubricated by the lubricant, the nut factor gets reduced. QM Yu et. Al. (2018).

IV FEATURE SELECTION

There are many feature selection process in machine learning process, each type of feature selection algorithm is deployed in different real time problems. Most applicable feature selection methods are filtering method, wrapper method and embedded methods. In filtering method each attribute of the dataset is provided with a rank based upon a threshold and reduce it to the most appropriate dataset for training and testing of the machine learning algorithm. The various filtering method present in machine learning process

are information gain, gain ratio, chi-square, correlation, fisher score and so on. Each of the filtering method have their own importance complexity and application.

A. Jović et al., 2020.

In wrapper method the successive feature selection method is used where a greedy search approach is used for the feature selection, here the various feature subgroups are repeatedly introduced in different machine learning classifier algorithm and the most ideal features are identified. The most common type of wrapper methods is recursive feature elimination, sequential feature selection algorithms and genetic algorithms. Embedded method is similar to that of the reinforcement learning.

Table 1 Values Obtained from Catboost Feature

Machine learning method	Features	Score for each Feature
Prediction value change	Surface_treatment	33.46
	Pitch	19.07
	Size	17.09
	Thread_tolerance	13.51
	Head Configuration	10.36
	Material	6.48

A. Fisher score method

To identify the most influencing we tried to deploy Fisher's criteria filtering method to choose the most appropriate features from the 11 features that could differentiate between the various friction value. The features extraction plays a major role in choosing the classification models. Therefore, the Fisher criterion score Equation (2) was selected to determine significant features from the feature vectors. Each feature had its own score, which was calculated as follows:

$$Fisher\,score = \frac{\mu_1 + \mu_2}{\sigma_1^2 + \sigma_2^2} \; [2]$$

where μ and σ indicate the mean and standard deviation, respectively, of the same class, and 1 and 2 represent classes 1 and 2, respectively. The selection of the remaining 5 features which are most correlated for the determination of the friction value are displayed in the correlation graph below. (fig 5).

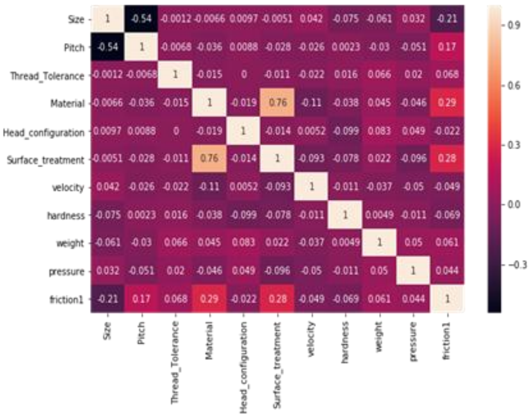

Fig 5 Correlation between various attribute

From the correlation graph it is very clear that there are five major factors which are predominate in determination of the coefficient of friction value they are, pitch, material, surface coating, head configuration and thread tolerance. Out of these five material, surface coating has a high value (0.76).

B. Catboost feature selection

Catboost algorithm is an ensemble method mainly used for classification and prediction. It has many techniques in built in python repository. The two types of feature selection methods of cat boost algorithm are prediction value technique and loss function change (Alvira Swalin, 2020). Prediction value change is a non- ranking technique used for the feature selection. It deploys a single feature at a time and analysis the change in the prediction by changing the weightage to the particular feature. Loss function technique cannot be applied for the categorical data since we find the importance of the feature using the difference between the pair of feature attributes (Raschka S., 2020). Hence, the prediction value change method was used to identify the feature importance. The results obtained for the various most important feature are tabulated above in Table 1.

V. RESULT AND DISCUSSION

Though there are many experimental method and finite element methods are available for the determination of the nut factor. But from this paper we could see that they are of high computational cost and have high time complexity. Similarly, not all the features which are associated in the torqueing mechanism is considered. This paper provided the following contribution for the future research in the same field.

1) The main three factors which has to be determined accurately are torque, preload and nut factor.
2) Other features which have a significant role in determination of the coefficient of friction are surface treatment of the bolt, pitch, thread tolerance, head configuration, material and size of the bolt used in the aerospace structures.
3) Out of the key features identified from the implementation surface treatment plays a major role in the coefficient friction.
4) The two feature extraction technique used for the selection of the important features where fisher score and prediction value change which has a less computational cost and time complexities.

VI. CONCLUSION

Determining torque, friction coefficient correctly for the torqueing process of fastener joints of engineering structures can help in avoiding the threaded bolt failure. The lubrication of fasteners or otherwise known as the surface treatment has a greater effect on the coefficient of friction which is evident from the two different feature extraction implemented in this paper. Though there are many factors associated to coefficient of friction like the pressure applied on threaded fastener while torqueing, weight of the individual bolt, velocity of the bolt torques and so on. Out of these through the features selection methods of machine learning method we could identify the most influencing features over coefficient of friction in torqueing mechanism of threaded fasteners in the aerospace structural joints.

Using machine learning feature extraction methods, we could achieve all the feature associated to friction factors in a single study instead of many individual experimental methods by which we reduced the computational and time complexity.

REFERENCES

1. George tools for life, " What can we learn about Torque"https://www.gedore-torque.com/service-centre/torque/ accessed on 16/februray/2020
2. Y.-J.Cha, et al.(2016),Vision-based detection of loosened bolts using the Hough transform and support vector machines, AutomationinConstruction,http://dx.doi.org/10.1016/j.autcon.2016.06.008
3. Keon-Hee Baek1, Nak-Tak Jeong1, Hee-Rok Hong1, Su-bin Choi1, Eun-Seong Lee1, Hyung-Min Kim1, Ji-Woon Kwon2, Seok-Yong Song3, Hong-Seok Jang3, Ho-Yong Lee4 and Myung-Won Suh5,*(2019)," Loosening mechanism of threaded fastener for complex structures" Journal of Mechanical Science and Technology 33 (4), 1689~1702
4. Jianjun Meng, Decang Li, Bowen Fan, Yatong Zhang (2018),"Torque waveform analysis and fastening method on invalid thread of track bolt" IOP Conf. Series: Materials Science and Engineering 397 (2018) 012118 doi:10.1088/1757-899X/397/1/012118
5. Deters .C, Lam .H, Secco E, Würdemann .H (2015), "Accurate Bolt Tightening Using Model-Free Fuzzy Control for Wind Turbine Hub Bearing Assembly", International Journal of Structural Integrity, Vol. 6 No. 1, pp. 26-39.
6. Dravid S., Tripathi K., Chouksey M. (2014), "Role of washers in controlling loosening of full threaded bolted joints." 2nd international conference on Innovations in Automation and Mechatronics Engineering ICIAME2014.
7. Althoefer K, Lara.B, Zweiri Y.H, Seneviratne L.D (2008), "Automated failure classification for assembly with self-tapping threaded fastening using artificial neural networks", Part C: J. Mechanical Engineering Science, Vol. 222.
8. Zou Q., SUN T.S., NASSAR S. A., BARBER G. C. and GUMUL A. K. (2007), "Effect of Lubrication on Friction and Torque-Tension Relationship in Threaded Fasteners", Tribology Transactions, Vol. 50, pp. 127-136.
9. Nicola Ivan Giannoccaro, Mongkorn Klingajay (2005),"Online Identification for the Automated Threaded Fastening Using GUI Format"https://www.intechopen.com/books/cutting_edge_robotics/online_identification_for_the_automated_threaded_fastening_using_gui_format (accessed on 12 January 2020)
10. Javier Camacho , Fernando Veiga ,Mari Luz Penalva , Alberto Diez-Olivan , Lutz Deitert and Norberto López de Lacalle , (2019) "On-Line Monitoring of Blind Fastener Installation Process", 12, 1157; doi:10.3390/ma12071157 Mackerle, J. Finite element analysis of fastening and joining: A bibliography (1990–2002). Int. J. Press. Vessels Pip. 2003, 80, 253–271. [CrossRef]
11. Louis, A. "Etude Experimental et Numérique du Procédé D'assemblage." Ph.D. Thesis, Université de Touluse, Touluse,France,2011.http://www.theses.fr/2011ISAT0020.pdf (accessed on 25 February 2019).
12. Huynh, T.C.; Dang, N.-L.; Kim, J.T. Preload monitoring in bolted connection using piezoelectric-based smart interface. Sensors 2018, 18, 2766. [CrossRef] [PubMed]
13. Jiménez-Peña, C.; Lavatelli, A.; Balcaen, R.; Rossi, B.; Debruyne, D. Model based bolt preload monitoring using digital image correlation. Proceedings 2018, 2, 514. [CrossRef]
14. Bhandari, V. B . Threaded Joints. Design of Machine, Elements; Tata McGraw Hill Education Private Limited: New Delhi, 1994.
15. Jadon, V. J.; Verma, S. Design of Threaded Fasteners. Analysis and Design of Machine Elements; I. K. International Publishing House: New Delhi, 2010.
16. SebastianRaschka,"feature selection categories", https://sebastianraschka.com/faq/docs/feature_sele_categories.html (accessed on 31st March 2020)
17. QM Yu, XJ Yang, HL Zhou, (2018), "An experimental study on the relationship between torque And preload of threaded connections",https://doi.org/10.1177/1687814018797033
18. Pradip D. Jamadar, Shirpur, Hemant K. Wagh Dr. Girish R. Desale, Dr. Kartikeya Tripathi , "Finite element based Pretension analysis of threaded Fasteners with Experimental Investigation", (2016) International Journal of Innovations in Engineering and Technology (IJIET) Volume 6 Issue ISSN: 2319 – 1058
19. A Jović, K. Brkić and N. Bogunović, "A review of feature selection methods with applications" (2020), https://bib.irb.hr/datoteka/763354.MIPRO_2015_JovicBrkicBogunovic.pdf
20. Alvira Swalin "Deep Dive into Catboost Functionalities for Model Interpretation",https://towardsdatascience.com/deep-dive-into-catboost-functionalities-for-model-interpretation-7cdef669aeed (accessed on 2nd April 2020)

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H. Setalaxmi, Mtech Computer Sccience and Engineering, (pursuing), "Effective Web Service by Colabrating NIMF and PCC" (2013), 6th National Conference on "Advances in computing & Networking(NCACNET), S.A Engineering College, Chennai 600077.

Dr. Sumithra M.D., PhD in computer science and engineering (Image processing), Assistant Professor, Computer Science Engineering, LBSITW, "Performace Analysis of LDA, Adaboost and Enssemble Bag classifiers for Automatically Recognizing Nine common Facial Expressions",(2018), Journal of computer science, 14(9):1226.1237, DOI:10.3844/jcssp.2018.126.1237, ISSN No.1552-6607, thesis work on "Novel approach to automatic facial expression using appearance feaures", Membership in ISTE

Anilkumar E.N., Assistant Professor, Mechanical Engineering, LBSITW, currently pursuing Ph.D. Industrial Engg. NIT Calicut, National Institute of Technology Calicut (NITC), Kerala."Sustainable Supply Chain Management A Literature Review and Implications For Future Research ,International Journal of System Dynamics Applications (IJSDA),(ESCI indexed),Vol. 8 issue 3, 2019,pp. 15-52." Analyzing the interactions among barriers of sustainable supply chain management practices: a case study", Journal of Manufacturing and Technology management (JMTM), (SCI indexed).