A Review Paper on Stress Concentration of Shoulder Fillet in Shaft

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Abstract— The Stress concentration effects are of primeval significance in many failure mechanisms, such as fatigue crack initiation or fracture of brittle components, However, the usual constant radius notch tip roots, used in most structural components to alleviate their stress concentration effects, do not minimize them. Geometrical features such as notches and corners give rise to stress concentrations. In manufacturing components these features are often designed with a constant radius; however it is already known that a more multipart shape, having a variable radius, can have a much lower stress concentration factor. Optimization of the fillet radius is important for reducing result of stress concentration.

Key words: Shoulder Fillet, Notch, Optimization, Stress Concentration, Fatigue

I. Introduction

A. *Shaft*

The Shaft is a common and important machine element. It is a revolving member, in general, has a round cross-section and is used to convey power. The shaft may be hollow or solid. The shaft is supported on bearing and it rotates a set of gears or pulleys for the reason of power transmission. The shaft is generally acted upon by bending moment, torsion and axial force. Design of shaft mainly involves in determining stresses at serious point in the shaft that is arising due to abovementioned loading. The design of these elements play very important role. In these all power transmission elements shaft is almost utilize in every machine or in every mechanical system. The ferrous, non-ferrous materials and nonmetals are used as shaft material depending on the purpose.

For the design of shaft following two methods are adopted:

- Design based on strength: In this method, design is carried out so that stress at any position of the shaft should not go beyond the material yield stress. However, no consideration for shaft deflection and shaft twist is incorporated.
- Design based on stiffness: Basic idea of design in such case depends on the permissible deflection and twist of the shaft.

There are various shaft components due to which the condition of discontinuity is employed in shaft. Also, from time to time geometrical considerations are major cause of discontinuity in shaft. To align the shaft, it must be joined with the help of key, so keyway is needed in both shaft and hub to fit the shaft. This is one kind of discontinuity which reduces the strength of the shaft. There are more than a few other type of discontinuities in shaft. Keys, groove, shoulder, pins, setscrews, these are the main components which also creates discontinuities in shaft. These discontinuities are necessary so it cannot be avoided but the same leads to the start of failure. These discontinuities weaken the shaft and considered to be major cause of failure. Most of the time the crack start is from these discontinuities. The stress is concentrated at these locations and it outcome into higher scale of stresses compare to other location in the shaft. Due to the higher scale of stresses the chances of failure are more at these locations. In static loading these discontinuities are less unsafe compare fatigue loading situation

Types of discontinuities present in shafts are:

1) Notch (Circumferential)
2) Groove (V, U, Square)
3) Shoulders
4) Steps
5) Keyway
6) Holes
7) Threads

Discontinuities can happen because of: Design of quick change in cross section, groove, holes, etc. where stress concentrations occur. Elements that roll and/or slide next to each other (bearings, gears, cams, etc.) under high contact pressure, growing concentrated subsurface contact stresses that can cause surface pitting or spelling after many cycles of the load. lack of care in locations of stamp marks, tool marks, scratches, and burrs; poor joint design; improper assembly; and other fabrication fault. Composition of the material itself as process by rolling, forging, casting, extrusion, drawing, heat treatment, etc. Microscopic and submicroscopic surface and subsurface discontinuities happen, such as inclusions of foreign material, alloy separation, void, hard precipitate particles, and crystal discontinuities

B. *Shoulder Fillet Radius*

Fillet is a rounding of an inner or outer corner of a part design. An inner or outer corner, with an angle or type of bevel, is called a "chamfer". Fillet geometry, when on an inner corner is a line of concave function, whereas a fillet on an outer curve is a line of convex function .The shoulder fillet is the type of stress concentration that is extra regularly encounter in machine design practice than any other. Shafts, axles, spindles, rotors, ands forth, typically involve a number of diameters linked by shoulders with curved fillets replacing the pointed corners

C. *Stress Concentration*

There are a variety of technique for evaluating stress concentrations in grooves due to geometrical irregularity such as opening and cracks. In design it is common to use the stress concentration factor, defined as the ratio of highest local stress to the nominal body or far field stress. The stress concentration factor can be evaluated by using computational method, elasticity theory and experimental stress analysis such as photo elasticity. Peterson (1961) has provide stress concentration factors for dissimilar geometric irregularities under different types of loadings. Wu and Mu (2003)developed simple technique to obtain stress concentration factors around circular holes situated in finite anisotropic plates and cylinders due to in plane loads. So from above dialogue it can be stated that the main reason of failure is the highly stressed part in any machine component. Stress concentration plays vital role in failure of Machine parts. This stress concentration must be reduced to prevent early failures. Geometrical discontinuities are main reason of stress concentration. So stress concentration is prime mode of failure in any machine components.

II. LITERATURE REVIEW

Literature review is carried out in the following areas:

- Failure analysis of shaft
- Shaft design
- Discontinuities
- Optimization Method

A. Literature review regarding failure analysis of shaft

Saleh A. Al-Fozan et.al (2005), Failure shaft visual examination shows shaft shear at two location, cracks were observed at key area & it is a fatigue failure .Observation from process data sheet vibration records & DPT test show crack at key position and grooves in sleeve area. Metallographic learning show shaft is Austenitic 316SS as per design. Visual examination of shaft shows some pitting marks, from EDX analysis the chloride iron were establish in pits marks. Because of this decay take place in shutdown period. Also key found loose in shaft which resulted in groove formation & accountable for crack initiation. Another possibility of localized corrosion is due to narrow crack on 316 L shaft is because of poor protection in presence of duplex stainless steel discharge pipe. In end combined act of environmental and stress cause crack beginning on shaft at key area and second probably due to key movable on shaft.

E. Rusiñski, J. Czmochowski, P. Moczko. (2007), This paper discuss the examination of dumping conveyor breakdown. It consist of two half shaft union the track grid to carriage. Due to slippage of one half shaft causes damage to slip out protection. To determine breakdown reason FEM strength calculation of steering shaft, metallographic examination is carried out. allocation of Huber-Misses stress of steering carriage for all required case of loading is carried out. FEM strength calculation indicate the bottom of groove stress go beyond the yield point. Metallographic examination shows fatigue breakdown features. Fatigue zone are small 2-4% of total fracture area its evidence of great strain on half shaft. It also demonstrate crack initiation from groove edge.

R.W. Fuller et.al (2009), In this paper breakdown analysis of mixer unit shaft made of AISI 303 stainless steel using conventional 14 step approach is carried out. Failed part is drive unit output shaft of 15 HP mixer unit.AISI304 shaft fail within 3 week of process. During examination it was found that shaft having a loose fit, weld plug were installed by same material AISI304,other factor such as weight of mixer, material & ambient temperature were not serious. A fact graphic study of shaft fracture surface to know type & origin of breakdown. Spectrometer reading was taken to determine material composition found not deviating from original values. Intergranular cracks were observed under. Weld plug used to overcome loose fit effect in failure. AISI304 not suitable for welding, instead. AISI 1018 cold drawn is improved option for the application region of industrial power transmissions

Deepan Marudachalam et.al (2011) ,This paper examine the failure of shaft working at spinning machine. The shaft is require to lift load of 960 kg through height of 230 mm. The shaft fail within 35 days of process. Failure take place at release groove provided for bearing seating. The small instantaneous zone indicate that short stress during failure. Endurance limit of shaft is calculated by using Goodman equation. Force analysis is carried out for both 22T & 90 T pulleys for both vertical & horizontal part.

V.S. Rocha et.al (2012), Has examine a fracture breakdown in a gearbox shaft of a scrap compressing machine. The shaft was made of a quenched as well as tempered SAE 1045 (ABNT 1045) steel. Scanning electron microscopy (SEM), chemical analysis by semi-quantitative EDS and optical microscopy (OM) were also used in order to get microstructure and hardness measurements. Micrographic analyses have also revealed a typical microstructure of tempered martensite The fracture mechanism has been found as brittle fracture by cleavage and the chemical analysis by EDS outcome have shown that it was steel with a important presence of iron and manganese. They found that the shaft, failed by fracture. The cracks originated from the groove area. It occurs in transangular way. The failures were due to fracture crack extension under torsional loading &impact loading

Zhang, Zhongjun Yin, Tian Han, Andy C Zhanqi.C. Tan (2013), Have carried out fracture analysis of wind turbine most important shaft. The shaft is made of 34CrNiMo6 steel with heat treatment. The loads from the main shaft to the hub include torsion, transverse moment and axial force. To decide the reason of shaft failure a series of experimental tests were conducted to evaluate the chemical composition and and mechanical properties. A detail analysis involving macroscopic feature and microstructure analysis of the material of the shaft was also performed. Theoretical stress calculations are also done for the purpose to find cause of crack. Visual inspection Microscopic examination, SEM observation is performed as a part of experimental work. Von mises failure theory is used to verify the failure of the shaft in stress analysis

Z. Domazet, F. Lukša , M. Bugarin.(2014), The breakdown of an overhead crane drive shaft and the failure of an overhead crane gearbox shaft, due to rotating-bending fatigue. The fracture of the overhead crane drive shaft originated in small radius fillet between two dissimilar diameters of the shaft. The crane was rated at 10 tons with span 20.5 m and handled about 100 lifts and transports per day, each lift averaging 5 tons. The stepped drive shaft utilize for an overhead crane trolley wheel fractured after 24 months of service. The electric motor power rating was 3 kW with an output speed of 940 rpm. The maximum travel speed of the trolley was 32 m/min. The shaft was made from quenched and tempered steel 25CrMo4 according to German standard

B. Literature Review Regarding Shaft Design

Dejan B. Momcliovic et.al (2014), Considered a case study of hydro turbine shaft. Highlighted the significance of combined load simulation for the calculation of machine parts load capability. The shaft with flange and high ratio of shaft/flange diameter is the subject of excessive calculation in order to find the reason of failure. The classic analytical calculation of this shaft uses the Peterson's elastic stress concentration factor and calculates stress concentration factors and highest stresses for different stress components of combined load and then calculate analytical values of total stress by the hypothesis of highest normal stress. On the other hand, presented FE Analysis simulates shaft stress state under real conditions of complex load by simultaneously applying all load components (bending, torsion and tension). Both of the computation are perform for few dissimilar radii in shaft-flange sections. The results are obtainable by comparative diagrams for obtained.

R. A. Gujar, S. V. Bhaskar (2013), Has perform the design of shaft under fatigue loading. They have study shaft employed in an Inertia dynamometer rotated at 1000rpm is studied. Considering the system, forces, torque acting on a shaft is used to estimate the stresses induced. Stress analysis also carried out by by FEA and the results are compare with the calculated values. Distortion energy theory is used for stress analysis. Endurance limit is calculated using Modified Goodman method fatigue factor of safety and theoretical number cycles sustained by the shaft before failure is estimated and compared results with FEA. Hence conclude that, the working alternating / mean stress within limit value and increased fatigue strength for infinite life below material endurance strength limit.

Maksym Gladskyi, Ali Fatemi (2013), Studied the notched fatigue behavior of low carbon steel specimen as well as load series effects under axial and torsional loadings. Fully reversed tests were conduct on thin-walled tubular specimens with or with no a transverse circular hole. A shear failure mechanism was observed for both smooth and notched specimens and under both axial and torsion loadings. Neuter’s rule yielded notch root stress and strain amplitudes close to the FEA results for both axial and torsion loadings

Zheng Songlin et.al (2011), Carry out a study on Lightweight design of automobile drive shaft based on characteristics of low amplitude load strengthening. For the purpose of light weighting design the new design method is applied on drive shafts. The technique is based on the low amplitude load strengthening characteristics of the material, and permit the stress, corresponding to test load, to enter into the strengthened range of the material. Under this condition, the light weighting design should guarantee that the reliability of the shaft is not impaired, even maximizes the strength potential of machine part in order to achieve the weight reduction and eventually to reduce the cost. The feasibility of the design is verified by means of strength analysis and modal analysis based on the CAD model of light weighted shaft. Load and stress characteristics of shaft are defined and then the proof stress location is examined by analytical stress calculation. The static strength computation is also done and strength examination is also done by FEA. The same is done for hollow shafts also and results are compared.

C. Literature Review Regarding Discontinuity

Sushanta Ghuku, Kashi Nath Saha (2016), It is well known that in a loaded structural member, reorganization of stresses occur near a discontinuity, thus increasing the induced stress value considerably over the nominal stress value. The paper presents an experimental study on existence of stress concentration in the surrounding area of drill hole present in master leaf of a leaf spring bundle. For the purpose of testing a leaf spring testing rig is set up and master leaf of an automobile leaf spring is procured. To examine the state of stress field produced in the master leaf spring, load-deflection behavior of the master leaf is first studied experimentally. Investigational stress concentration factors are obtained by mounting strain gauges at different position, around the central drill hole of the master leaf. In corresponding theoretical analysis, the master leaf spring is modeled as a curved beam with a circular hole on its center line subjected to combined bending and stretching.

Sushanta Ghukua (2016) It is well identified that in a loaded structural member, reorganization of stresses occur near a discontinuity, thus rising the induced stress value considerably over the nominal stress value. The paper presents an experimental study on existence of stress concentration in the vicinity of drill hole present in master leaf of a leaf spring bundle. For the reason of experimentation a leaf spring testing rig is set up and master leaf of an automobile leaf spring is procured. To investigate the state of stress field produced in the master leaf spring, load-deflection behavior of the master leaf is first studied experimentally. Experimental stress concentration factors are obtained by mounting strain gauges at different locations, around the central drill hole of the master leaf. In corresponding theoretical analysis, the master leaf spring is modeled as a curved beam with a circular hole on its centre line subjected to combined bending and stretching. Theoretical and experimental stress concentration factors are reported in an appropriate form which will facilitate to undertake rigorous theoretical analysis of stress distribution around geometric discontinuities in beam under different loading conditions.

Busuioceanu (Grigorie) Paraschivaa, Stefanescu Mariana-Florentinab, Ghencea Adrianc (2016), This paper is indented to emphasize the possibilities to show the influence of present principles to improve or change design technique of pressure vessel, in spite of all troubles related to recent inspection programs for metallic pressure containment vessels and tanks which have revealed cracking and damage in a considerable number of the vessels inspected. On the one hand, it identifies and proposes the approach of a new research concerning the decrease of the following phenomena: cracking, stress, stress concentration, defective Design, corrosion, fatigue, creep, and other serious damage problems. On the other hand, the paper reflects the important role of good practice, careful process, regular maintenance, and adherence to the recommendations and rule developed for susceptible applications. We investigate how can all of this troubles influences future studies.

V. G. Aradhye1 ,S.S.Kulkarni2 (2015),Stress concentration around holes is an significant problem for mechanical engineering and civil engineering and used in a variety of engineering applications. Abrupt change in geometry of part is known as stress concentration. In this paper, stress concentration of rectangular isotropic and orthotropic plate with multiple circular holes are calculated in tensile loading on computerized Universal Testing Machine (UTM) and Strain gauge indicator. The material used for the plate is Mild steel in isotropic nature and Carbon epoxy in orthotropic nature. Experimental outcome are compared with finite element ANSYS software

Adis J. Muminovic*, Isad Saric, Nedzad Repcic (2014), Small computer software for analysis of stress concentration factors was developed at Faculty of Mechanical Engineering Sarajevo. Software name is AlfaK. Developing process of the software was presented in previous papers of same authors, in this paper testing of the software was done using numerical analysis. To test correctness of AlfaK software, analysis of stress concentration factors was done numerically using CATIA V5 commercial software for characteristic geometrical alter in form. Obtained data from numerical analysis are used for comparison with outcome from AlfaK, and on that way, Scorrectness of AlfaK software is investigated

Murat Tolga Ozkan1, Cengiz Eldem1, Ýsmail Sahin1 (2014), When designing machine equipment, geometrical figures or discontinuities such as notches, holes, steps and curves can occur. Sudden cross-section change, discontinuities and force flows cause concentrations, particularly in the stress region. Stress concentrations may be formed due to dimensional features of a material or directions of applied forces. Such stress concentrations are considered as they have a notch effect on the material. The notch result may lead to a breaking and distortion of a material. In this study, a mathematical model estimating the notch-factor values for a grooved round bar in torsion, a round shaft with a transverse hole in torsion and a round shaft with a shoulder fillet in torsion, using artificial neural networks (ANN)is introduced.

Choon Tae Lee1, Myung Soo Kim2 and Tae Hyun Baek3 (2014), This paper presents for determining the stress concentration around a circular and an elliptical hole in a finite-width, tensile loaded plate by the hybrid experimental-numerical method. In order to see the effects of varying stress field, different numbers of terms in a power-series representation of the complex type stress function are tested. The hybrid results are extremely comparable to those predicted by FEA. The result shows that this approach is effective and promising since isochromatic data along the straight lines in photo elasticity can be conveniently measured by use of phase shifting photo elasticity.

Jagtap S.P.*, Chhapkhane N.K. (2013), Many components fail in process due to the phenomenon of stress concentration. In this paper the experimental and numerical studies were conduct to examine the stress concentration around a cutout in composite panel. By the application of Photo Stress coating material, the stress measurements were performed in the vicinity of the notches. The stress at the edge of the notch is peak stress into the composite panel. These peak stresses were divided by the corresponding nominal far field stresses to get the stress concentration factors for specimen loaded in compression. A mesh of quadrilateral elements was used to model specimen with double notches. The two dimensional finite element simulations were perform using ABAQUS general-purpose computer program. The experimental results of peak stress or maximum stress were compared with finite element solutions performed on the specimen geometries and loadings similar to the ones used in the experiments. The stresses were used to calculate the stress concentration factors

Hitham M. Tlilan et.al (2011), The elastic new strain-concentration factor (SNCF) of cylindrical bars by circumferential flat-bottom groove is studied. This new SNCF has been defined under triaxial stress state. The employed specimens have constant groove depth with net part and gross diameters of 10.0 and 16.7 mm, respectively. The length of flatness ao has been varied form 0.0 ~12.5 mm to study the elastic SNCF of this type of geometrical irregularities. The results that the elastic new SNCF rapidly drops from its elastic value of the groove with ao = 0.0, i.e. circumferential U-notch, and reaches minimum value at ao = 2 mm. After that the elastic new SNCF becomes almost constant with increasing flatness length (ao). The value of tensile load at yielding at the groove root increases with increasing ao. The current results show that severity of the notch decreases with growing flatness length

John M Considine1, David W Vahey1, James W Evans1, Kevin T Turner2 and Robert E Rowlands (2011), Cellulosic webs, such as paper materials, are collected of an interwoven, bonded network of cellulose fibers. Strength controlling parameter in these webs are influenced by constituent fibers and method of processing and manufacture. in its place of estimating the effect on tensile strength of each processing/manufacturing variable, this study modifies and evaluate the point stress criteria and average stress criteria models used to estimate defect-free (i.e., maximum possible) tensile strength and the inherent size of the cumulative effect of strength-limiting defects. The two major modification to these models were to assume that defect-free tensile strength was unidentified and that unmatched tensile strength was reduced by the presence of inherent defects. These modifications allow the calculation of inherent defect size and defect-free tensile strength by characterizing the tensile strength of the web in the presence of stress concentrations associated with holes of different radius. The models were applied to seven paper materials including lightweight, commercial papers, linerboards, and cylinder boards; estimated inherent defect sizes variety from 0.1 to 1.5 mm.

A. M. Wahl et.al (2010), The problem of stress-concentration effects, produced by holes and notches in bars under tension is, of interest to machine designers. The present paper describes photo elastic tests and strain measurements to determine these effects more accurately than has been done heretofore, a more accurate extrapolation method being employed in connection with fringe photographs. Stress-concentration factors thus determined were, in general, higher than those obtained by previous investigators. In cases where mathematical calculations were available, the tests checked these. Empirical equations for use in calculation are also given.

D. D. Literature review regarding Optimization methods using for Stress Concentration

Kanak Kalita (2014), The present study aims at reducing this stress concentration around the central hole by introduction of a proposed scheme of auxiliary holes.

Reduction in stress concentration with symmetric and asymmetric auxiliary holes is studied. Findings of the study are made available here in both numerical data and graphical form. Any abrupt change in dimensions gives rise to high stresses around the discontinuity and change in stress flow lines is seen. Through gradual change in the structure reduction in these accumulated stresses is seen. In case of plates with central cutouts this can be achieved by future scheme of drilling auxiliary holes around the central hole periphery. The distance should not be less than 0.5 times the dimension of the cutout. In general model 2 and model 3 seems to work better at cutout proximity of about 0.5 times the central cutout dimension. The removal of material by inclusion of auxiliary holes to reduce stress is practically more suitable for plate with infinite dimension due to sufficient availability of space and would lower the stress by significant amount

David Taylor, Andrew Kelly, Matteo Toso, Luca Susmel (2012), The effects of stress concentration features can be very much reduced by making subtle changes to their shapes, altering local curvature to make a variable-radius notch as an alternative of a constant-radius notch. The Local Curvature Method (LCM) is able of creating variable-radius notches with greatly reduced maximum stresses, using a very simple approach based on post-processing data from a finite element analysis of a conventional constant-radius notch. This approach could be very useful in industrial situation where there is only limited access to computing resources. The mode Frontier software can be used where more extensive computing resources are available, to conduct a systematic search covering a wide range of variable-radius designs. This approach was able to find solution which was slightly superior to those of the LCM.

Pedersen, Niels Leergaard (2010), Keys and keyways are one of the most ordinary shaft–hub connections. Despite this fact very little numerical analysis has been reported. The design is often regulated by standards that are almost half a century old, and most results reported in the literature are based on experimental photo elastic analysis. The present paper shows how numerical finite element (FE) analysis can get better the prediction of stress concentration in the keyway. Using shape optimization and the simple super elliptical shape, it is shown that the fatigue life of a keyway can be greatly better with up to a 50 per cent reduction in the maximum stress level. The design changes are simple and therefore practical to realize with only two active design parameters. This paper has demonstrated how it is rather simple to find the stress concentration factors for the prismatic part of a keyway in pure torsion. Using the keyway design as defined by DIN 6885 the result of the paper is a easy algebraic expression for the stress concentration factor. Also presented is a band within which the stress concentration factors for the DIN 6885 lies.

F O Sonmez (2009) Optimization is attain using a stochastic global search algorithm called the direct search simulated annealing. The boundary is defined using spline curves passing through a number of key points. The method is also applicable to shape optimization problems in which geometric constraints are imposed and, for this cause, tangential stress is not uniform along the optimal fillet boundary. Optimal shapes are get for flat and round bars subject to axial, bending, torsional, or combined loads. The outcome show that stress concentration factors close to one can be achieved even for bars with significant variations in cross-section. Besides, the region occupied by the optimum fillets is much smaller in comparison to circular or elliptical ones. In this study, global shape optimization of shoulder fillets in flat and round bars was attain. Although optimum fillet design of flat bars was a problem that was considered by many researchers before, improved results were get in this study by applying a global shape optimization procedure. As for the optimum shape design of shouldered round bars, the results obtain in this study are remarkable. The stress concentration factors ,Kq, in the optimal-shaped round bars were obtained to be 1.0 for axial, torsional, and pure bending load cases for the chosen geometry. For combined loading, Kq was close to 1.0. Therefore, make use of of this algorithm may considerably increase fatigue strength and reliability of machine parts.

III. Research Gap

From literature review the research gap has been found out and stated below:

- Optimization of constant radius of fillet shoulder of shaft and this radius used as post procedure data for Local Curvature Method & Mattheck method is not observed with actual part of any mechanical system.
- 2)The work concerning various loading in shaft design with consideration of different variable radius alteration method in one shaft is rarely observed
- In any of the above literature it is not clearly been stated the criterion for selecting the suitable radius for any shaft. separate technical base for selection of a particular variable radius is not experiential in any literatures.

IV. Conclusion

From literature survey Stress concentration for different geometric configurations and its relation to fatigue strength reduction factor in addition to notch sensitivity have been discussed. Methods of reducing stress concentration have been verified and a theoretical foundation for stress concentration was considered.

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