Design, Fabricated, and Trial on a Fatigue Test Machine

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Abstract. Accidents can be caused by the use of components that exceed the fatigue life that can be predicted with a fatigue test. The limitations of the fatigue test machine encourage industry not to test the fatigue life of its products, because consumers do not necessarily ask for it. The availability of functional and affordable fatigue test machines for industry and universities greatly supports the realization of predictive fatigue life component information. The design, manufacture, and trial of fatigue test machine are done with PVC and Nylon plastics. The specimen is machined using a CNC machine, because the cross section is radius in the middle symmetrical, which is difficult to be conventionally made. The construction of the shaft bearing is capable of rotating the specimen until the specimen is broken. The fatigue test machine is equipped with a magnetic sensor to count specimen rotation. The loading of the specimen is used flexible bearings and coupling, so that the load is fully directed to it. The speed variation is regulated by a DC motor and the load variation is mechanically regulated. The fatigue test results on PVC and Nylon materials show a fatigue life that decreases with increasing loads plotted in the S-N curve.

Abstrak. Kecelakaan dapat diakibatkan oleh pemakaian komponen yang melebihi umur lelah yang dapat diprediksi dengan uji lelah. Keterbatasan mesin uji lelah mendorong industri tidak selalu menguji umur lelah produknya, karena konsumen belum tentu memintanya. Tersedianya mesin uji lelah yang fungsional dan terjangkau bagi industri dan perguruan tinggi sangat menunjang terwujudnya informasi prediksi umur lelah komponen. Desain, pembuatan, dan percobaan mesin uji lelah dilakukan dengan plastik PVC dan Nylon. Spesimen dibubut menggunakan mesin CNC, karena penampangnya berbentuk radius yang pada bagian tengahnya simetris, yang sulit dibubut secara konvensional. Konstruksi bantalan poros dibuat mampu memutar spesimen hingga spesimen tersebut patah. Mesin uji lelah dilengkapi dengan sensor magnetik untuk menghitung putaran spesimen. Pembebanan spesimen digunakan bantalan dan kopling fleksibel, agar beban sepenuhnya terarah padanya. Variasi kecepatan diatur oleh motor DC dan variasi beban diatur secara mekanis. Hasil uji lelah pada bahan PVC dan Nylon menunjukkan umur lelah yang menurun dengan semakin naiknya pembebanan yang diplot dalam kurva S-N.

Keywords: kecelakaan, umur lelah, mesin uji lelah, spesimen PVC dan Nylon, mesin CNC, kurva S-N

Introduction

By making possible prototypes of fatigue test machine, students' opportunities to practice on the topic of fatigue test can be accomplished and equip them with sufficient knowledge to work in industry which in turn can always be aware that every component it produces has certain fatigue life that must be realized and prevented by maintenance and/or its replacement before an accident occurs. So efforts to design, create, and test on some technical materials should be supported for the realization of the intended purpose. Specific objectives can be achieved if the prototypes can be mass-produced so as to achieve the production efficiency and the price of the products that are affordable to the lower-middle-class industries that are not necessarily prioritizing the prevention of an accident rather than merely prioritizing the component business without providing assurance or information on the fatigue life of a component which it produces. Research on a variety of engineering materials (plastics, metals, ceramics, and composites) becomes urgent to be published primarily to industry and potential users of a component product made by industry.

With the expected fatigue life of a component, a transaction with a price may be realistic for its usage services, which in the meantime if asked by a prospective consumer to a producer only obtains answers depending on many things, usage or loading conditions, and the environment. It is very different if fatigue life prediction is reported that the results of a fatigue test of a material under predicted or simulated conditions are close to real conditions in the field. With these conditions, the information obtained by consumers with relevant data, so that the transaction for a price can be proportional with the benefits.

An illustration: the design of an aircraft takes about 3-4 years to obtain a complete design. Manufacturers of an aircraft take about 2-3 years of support technology required, while the operation and maintenance of aircraft for example can reach 15 to 25 years, then with one case only an accident, consequently the entire investment of an aircraft will disappear instantly, regardless the preparation of an insurance claim, so with a plane crash can make the investment turns to zero, which may be the cause of fatigue life that is violated due to the passing limit of the resistance of a component.

Related Works

When fatigue stress is induced on a material due to the action of force reversing and fluctuating, a failure known as fatigue failure takes place. The study and test conducted so far shows that fatigue failure cannot be predicted accurately since material failure under fatigue are affected not by just reversal loading alone but also the number of revolution (cycle per minute) and fluctuating stress and other factors such as temperature, atmospheric condition, both internal and external defect on material subjected under fatigue stress. Such defect includes notch, inclusion, stress concentration and inhomogeneity.

Many mechanical components experience stress fluctuations in operations, resulting in failure. The design of fatigue test machine [1] of the electric motor shaft is directly connected to the bearing and the specimen clamp which allows the axle to not be flexible, during a symmetric deflection at the time of loading at both ends of the specimen.

Fatigue test machine are classified on purpose, load type and loading as important factors in design and critical loading systems based on the type of force: spring, gravity, centrifugal, hydraulic, pneumatic, and electro-magnetic [2]. The mode of loading is strongly influenced by the source of the applied force.

Fatigue test machine require high design costs with specimens subjected to repeated fluctuating stresses and the number of cycles counted until the specimen breaks [3]. Fatigue test machine design requires high cost for specimen conditions subjected to repeated fluctuating stresses and simultaneously counts the number of cycles until the specimen becomes broken.

The experiment of observing the phenomenon of fatigue failure in the behavior of engineering materials with fatigue load is the S-N diagram, which S and N reflect the level of stress and number of cycles. Due to the uncertainty of material characteristics, a large number of specimens were tested at different stress levels to produce an S-log N diagram. The cost range for typical educational fatigue test equipment is from $ 10,500 to $ 32,500 (Rp 141750000-438750000). The machine is essentially an adaptation of the R. R. Moore's industrial fatigue test machine that costs over $ 150,000 (Rp 2025000000). The goal is to produce an affordable and reliable machine version [4]. Examples of specimen tests are divided into 2 types to demonstrate the smooth and rough surface effects of fatigue test results. Typical educational fatigue test equipment has been manufactured at a price much cheaper than the machine used in the industry.

Machine components as specimens are subjected to repeated varying forces or the fluctuations loading with a certain quantity and the number of stress cycles to a damaged specimen is counted. Analysis of the performance of the fatigue test machine is to determine the efficiency of the machine, various specimen materials tested by the initial test, with a stress value smaller than the tensile strength of the material. Furthermore, the selected stress is smaller than that used in the first. The process is repeated with a decreasing stress value and the result is plotted as S-N curve [5]. The curve of a number of specimens yields a correlation between S and N as an S-N curve.

Failure of material fatigue is reported to cause > 75% of documented failures that mostly occur suddenly. Fatigue life of a component can be obtained from fatigue test machine based on loading condition. Low cost four points loading rotating bending on fatigue test machine is tested. The design principle is based on the adaptation of the technical theory of elastic beam bending. Machine performance was evaluated by modifying the test specimen. It is observed that the machine has the potential of producing varying bending and torsion stress. The diameter specimens between 6 and 8 mm are subjected to loads between 30 and 90kgs and the number of failure cycles is obtained from both the experimental and theoretical calculations with the result being close. Machine has the advantage: ease of operation, maintenance, and safely for use [6]. A rotating bending on fatigue test machine design with varying bending and torsion stress has been tested and is easy to operate.

The objective of the study was to develop low-cost rotating fatigue bending machines and to test multiple specimens simultaneously and at different temperatures. The machine can be used to replace many test parameters and tends to be tested at high temperatures [7]. A development of fatigue bending machines for many specimens simultaneously and at different temperatures is performed with low-cost.

The lack of concepts in the testing industry is a fatigue test machine that can simultaneously test the fatigue strength of 2 specimens at the same time [8].

An effort to increase efficiency is by testing fatigue for 2 specimens at once.

Fatigue can result in a failure of > 80% in a material that has a repetitive load that occurs under the tensile strength of the material. So the solution of the problem is to know fatigue life material from fatigue test machine. There are many types of fatigue test machine for loading on the shafts of the car that are subjected to bending and torsion simultaneously. The development of fatigue test machine design for the combination of bending and torsion simultaneously with the cheaper price becomes a further consideration [9]. A proposed fatigue test machine design with combination of bending and torsion simultaneously.

Brass alloys have high electrical and thermal conductivity, but fatigue performance is not very well explored in the literature. Fatigue behavior of brass with 70%-Cu and 30%-Zn compositions has been studied with the aim of studying the factors: annealing, corrosion, and surface roughness that affect fatigue life. The endurance limit of the specimen has been determined by testing under different loads on the fatigue test machine and the life cycle of each specimen is taken after the failure of the specimen. Endurance limit is defined as alternating stress which causes failure after a certain number of cycles. Annealing was performed by heating the specimen at 480ºC for 1 hour and then allowing the specimen to cool down in the control atmosphere for 3 days. Fatigue tests for annealing specimens were performed and changes in fatigue endurance were investigated. One (1) mm groove specimens were prepared and specimen endurance limits were determined by testing under different loads on the fatigue test machine and the life cycle of each specimen was taken after the fracture occurred on the specimen. The corrosion attack was obtained by immersing the specimen in brine for 14 days to determine the effect of corrosion on the fatigue material life. The corrosion agent is a NaCl solution with a pH of about 6.5-6.8 and a solution concentration of 38%. Fatigue tests at 2800 rpm at room temperature and without environmental moisture control were performed on corroded, non-corrosive specimens to investigate the corrosion effect on fatigue resistance. Concluded fatigue life behaviors fatigue change due to annealing, groove, and corrosion attack on the surface of brass material. The best way to minimize fatigue failure is to reduce avoidable stress raisers through good design and prevention of stress raisers by proper machining and fabrication. Corrosive environments result in pitting on metal surfaces which acts as a notch as a stressor and has a negative effect on the fatigue properties as it accelerates the initiation and fatigue propagation levels that decrease the fatigue life of the materials. Relative humidity (19.5-100%) has no significant effect on fatigue life and is negligible [10]. The effect of corrosion and grooved surfaces decreases the brass fatigue strength.

From various literature reviews obtained comparators to show that the use of flexible coupling after the electric motor is important so that loading can be given symmetrically. The loading mode is very influential from the applied force source, mechanical force is generally stable and widely used. Efforts to design fatigue test machine with cheaper cost continues to be developed. Fluctuation load and counts of N must be performed simultaneously during loading. The surface of the fatigued test specimen should be as smooth as possible to obtain optimum results. The fatigue test result of a specimen is shown in the form of fluctuation stress curve to cycle number (S-N curve). Bending and torsion variations can be applied to fatigue test machine design with easy operation. Development of fatigue bending machines for the use of many specimens simultaneously and at different temperatures can be achieved with low-cost. Increased efficiency can be achieved by testing 2 fatigue test specimens at once. The effect of groove and corrosion treatment on brass has been done fatigue test.

Literature Review

Fatigue of a material is caused by the cycling/alternating load, for example on springs, saw blades, bicycle pedals, bolts, and shafts [11]. Some practical applications involve the cyclical load at a constant amplitude, but the load is irregular over the more frequent time encountered. Some examples of irregular loading of time are on a steering wheel of the car as the stress of time function, the vibration due to the roughness of the road, and due to the maneuvering of the vehicle, as well as the load for each round of a helicopter rotor [12].

In fatigue test machine specimens/rods rotated by R.R. Moore is equipped with: an electric circuit breaker, when the specimen is broken, the shaft is flexed and the breaker switch works, the revolution counter, the flexible coupling, and the ball bearings [12-13].

Standard fatigue test machine for rotating rod by R.R. Moore is loading by: 0.05, 0.1, 0.2, 0.5, 1, 2, 5, and 10 kg; rotation 500-10,000 rpm; standard specimen length 87.3 mm or more 25.4 mm without affecting machine calibration, the largest tapered-end specimen diameter is 12.2 mm and at both ends of the cylindrical handle (straight shank specimen), and the center radius is 88.9-254 mm [14-15].

The example plot of the stress curve and the number of cycles of a fatigue test (S-N curve) for steel 1047 material indicates that for steel material has an endurance limit of about 330 MPa, ranging from cycles of 10^6 to $1.4x10^8$ and for Aluminium 2014-T6 is not showing an endurance limit, but decreases with increasing number of rotations [16].

Factors that affect fatigue life include: the amount of stress amplitude given, with the higher the stress given, the more decreased fatigue strength; the surface of the work piece, the more rough, the decreased fatigue life; the shape of the design given the fillet/radius on the cross-sectional changes, indicating that the less stress concentration that can increase its fatigue life; the presence of surface hardening, as shoot peened, the fatigue life is increased due to compression residual stress on surface [13].

The non-corrosive surface has higher fatigue strength than the surface in sea water [17].

The case studies of properties and fatigue tests on steel, Aluminium and plastic show that: steel has a fatigue limit of 450 MPa in $100x10^6$ cycles, Aluminium has a fatigue limit of 115 MPa in $100x10^6$ cycles, and PVC plastic has a 10 MPa fatigue limit in $100x10^6$ cycles, indicating that the 3 materials have the same fatigue life limit for different loads or for the same load with different fatigue life [18].

Materials and Methods

Specimen materials in fatigue test are polyvinyl chloride (PVC) and Nylon plastics with standard form which is cylindrical in the middle with radius in longitudinal direction, so preparation is required by using a CNC lathe to make radius in the longitudinal direction (along the specimen axis).

The preferred method is the design of a fatigue test machine with rotating specimens following the R.R. Moore concept. The design of a fatigue test machine using a DC motor as a rotation drive of its specimen can be changed rotation speed without using a belt-pulley mechanism. Between the electric motor shaft and the specimen drive shaft are connected to a flexible coupling using rubber from a tire of a motor vehicle. The flexibility of the drive shaft is to follow the flexibility of the specimen before the break, allowing the loading to be given symmetrically. Symmetric loading is possible by making two pairs of transverse shafts that are balanced on the swing construction of both ends of the specimen end using 2 chucks of a drill bit. The loading is given by mechanical loading of a half-kg steel weight, followed by a multiple of each kg to a maximum load of 10 kg. The weighting is made of a construction that can adapt when the specimen test begins to flex. When the specimen is broken on a particular deflection, it is connected to a limit switch that can break current on the electric motor, so that the electric supply is up and the motor stops for rotating. The rotation of the specimen axis is counted with a digital display that records the amount of rotation achieved through a magnetic sensor at one end of the shaft. With the end of a rotation specimen, the digital display shows the recording of the specimen rotation as a reflection of the fatigue life specimen. A number of specimens were tested for fatigue in order to plot the S-N curve as fatigue properties of a material.

Results and Discussions

Fatigue test specimens derived from PVC and Nylon plastics prepared by CNC lathe to meet the radius shape in the longitudinal direction (R = 254mm) and achieve a smoothness of approximately N5-N6 as shown in Figure 1. The capability of the fatigue test machine is for a maximum specimen size of 130mm in length, and 13mm in diameter on both grips.

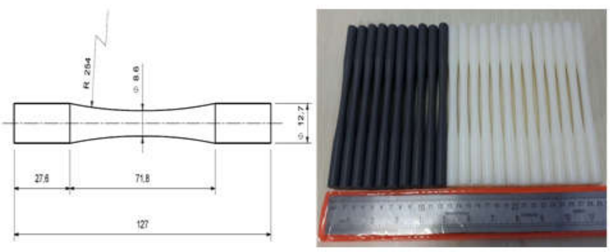

Figure1. Specimens for fatigue test as a result of CNC lathe work (PVC specimens: dark grey, and Nylon specimens: white)

Figure 2. DC electric motors for driving the fatigue test machine and its controller 3 kW [19]

Fatigue test machine using DC motor with 3 kW, 48V, speed between 3000 and 5000 rpm, 10 Nm of torque, and using air cooling as shown in Figure 2.

Grips for holding both ends of the fatigue test specimen were used two available drill chucks on the market as shown in Figure 3a [20]. Behind the two drill chucks is paired with two types of single raw ball bearing for hanging a weighting load to adapt when the fatigue test specimen strikes before breaking as shown in Figure 3b [20]. Four pillow block bearings are used to support the swing axle inside the tube supported by 2 bearings to allow the shaft to rotate and also swing if the fatigue test specimen bends because the loading or specimen becomes broken as Figure 3c [20].

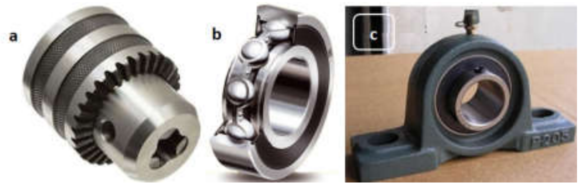

Figure 3. (a) Grip of a drill chuck, (b) Single raw ball bearing, and (c) Pillow block bearings [20]

The loading construction is applied to a pair of bearings as Figure 4a behind the drill chuck symmetrically connected through the weights load as shown in Figure 4b.

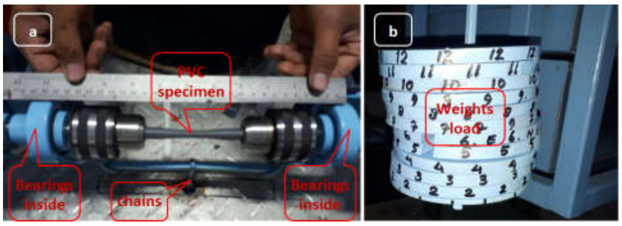

Figure 4. Construction of loading through a pair of symmetry bearing (a) connected to weights load (b)

The flexible coupling made from the tire of a motor vehicle is working well, testing for about 10 hours with 9 specimens shows no sign of damage at all which means the flexibility due to loading up to 10 kg is not an obstacle at all as shown in Figure 5. It appears from the front view that the axis of the motor to the axis of the drill chuck is no longer aligned, the 2 tubes supporting both shafts are both moving down towards the specimen due to the loading behind both drill chucks, and consequently the rubber clutch made of tire become elevated, while the height of the motor axis is fixed.

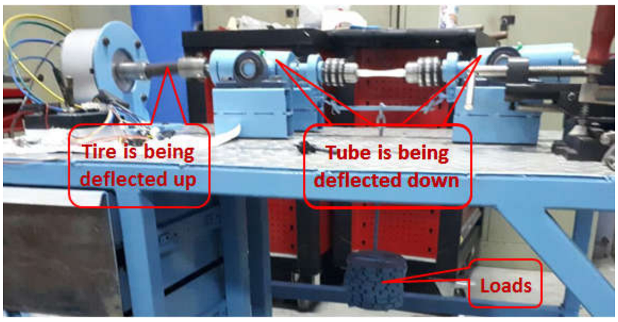

Figure 5. The flexible coupling made of tire rubber is being deflected up and the two axle support tubes are both moving down towards the specimen due to loading behind both drill chucks

After fatigue testing, the specimen becomes broken in the middle of the specimen length because stress concentration lies in the center of the specimen as Figure 6a, and the construction of the fatigue test machine from front view as shown in Figure 6b.

Figure 6. (a) The specimen is broken in the middle of the specimen length, and (b) the construction of the fatigue test machine from the front view

The magnetic count sensor of the rotation of specimen is placed at the other end of the shaft other than that connected to a DC motor about 3.5 mm apart from the object affecting the magnetic field of the sensor marked by the LED (light emitting diode) on if the magnetic field is interrupted which means count the rotation is working as shown in Figure 7a. The display of microcontroller (µC) console can be connected to an Android mobile phone with internet connection via Google chrome with code 192.168. 4.1 followed by enter to menu µC, reset, type msg 1, and enter, display second reading on 64 and rotation on 1178 as Figure 7b.

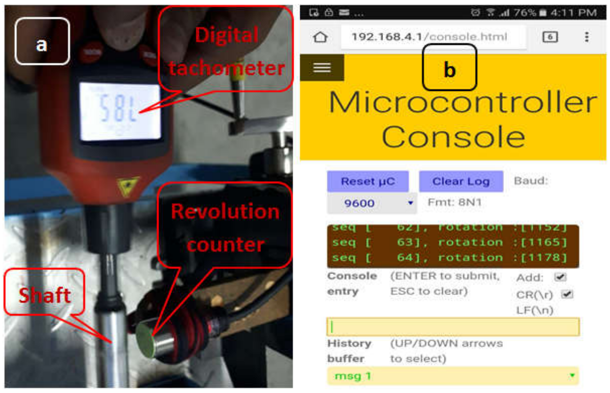

Figure 7. (a) The revolution counter and (b) microcontroller console

The DC motor trial with batteries to be assembled with a specimen on 2 drill chucks, followed by a pair of single row ball bearings and supported by 4 pillow blocks is shown in Figure 8. The initial trials of fatigue test machine were carried out on specimens of PVC type plastic material showing that respectively alternating stress, S of 201, 165, 147, 129, 111, and 94 MPa obtained N worth 2488, 9540, 11312, 13435, 18574, and 34165 cycles for PVC, and S for Nylon of 201, 183, 165, and 147 MPa obtained N worth 1115, 1342, 4743, and 8773 cycles shown on the curve as Figure 9.

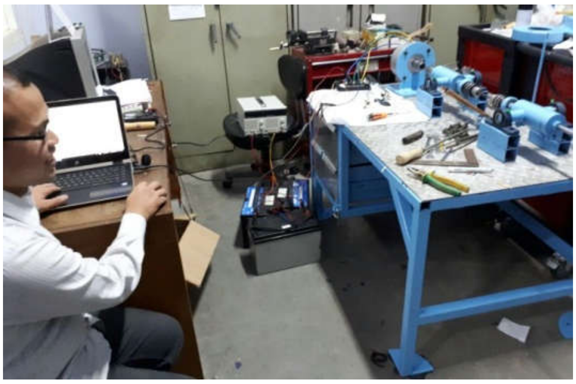

Figure 8. Trial of DC motor to be assembled with other components

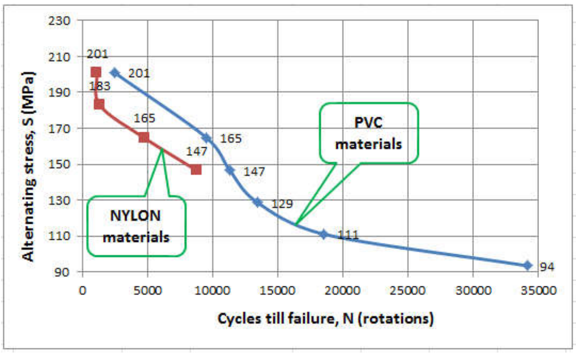

Figure 9. Fatigue test results, S-N curves

Conclusions

The results of the design, fabrication, and fatigue test machine trials can be summarized as: (1) trial results on the fatigue test machine show that machine capability for standard specimen size R.R. Moore with diameter 12.7 mm and length 130mm, DC power 3kW, 48A, torque 10Nm, and 3000-5000 rpm, (2) fatigue test results of PVC material showed that the maximum alternating stress was achieved at 201 MPa, and 34165 cycles for 6 times testing, (3) flexible coupling made of tire rubber after working for about 10 hours without showing any sign of damage, and (4) testing time in fatigue test machine experiments using Nylon material takes shorter than PVC material.

Recommendation of follow-up on the conclusion of a trial of a fatigue test machine on a wider load variable, and AC power supply needed with rectifier for testing takes longer, or the battery used to test discharge during use, and further suggestions should be continued fatigue test by Nylon materials.

Acknowledgement

This research is supported by the Directorate General of Higher Education, Ministry of Research, Technology, and Higher Education of Indonesia with research grant of SPPK 7832/PL2.1/HK/2017. The authors thank to Mr. Iskandar from the State Polytechnic of Malang for his assistance.

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