EAN 2012
50th annual coference on experimental stress analysis

Component fatigue testing on the electrodynamics vibration machines

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Abstract: This article describes different approach for component fatigue testing on standard electrodynamics vibration machines. For fatigue testing is used loading of parts under resonance frequency with suitable modification of initial condition – especially geometry, fixing points and additional mass. Detailed description of more experiment example shows advantages and limitation of these methods, which are suitable mainly for small components with high rigidity.

Keywords: Component fatigue testing, Resonant machines, Electrodynamics shakers

1. Introduction

The designers and test engineers are often faced to problem how to find more robust components, parts and its connections from the fatigue point of view. The fatigue properties of components and its joints cannot be easy compared based only on the result from the static test. The fatigue damage there generates often completely different type of failure mode with static test. There can be said that the fatigue testing is much more complicated as the static. Typically there are needed between hundred thousand and millions of load cycles and the variance of the result are much bigger that in static loading. Thanks these influence there are needed more samples and more time for relevant result.

2. Testing machine used for fatigue tests

There are in the real test field used for the fatigue testing pneumatic or hydraulic test cylinders. These machines are very universal, but its main disadvantage is relatively low running frequency (max. approx. 50Hz) and high power consumption. More as fifty years there are also used for fatigue test resonant testing machines. The main advantage is high time and energy efficiency. Typical running frequency is about 50-300Hz, power consumption about 50-1000W, that is around 50-10% of consumption of hydraulic machines. These principle need for the testing mostly samples with high rigidity.

Because these special test machines are not so common in all test labs the same as in Swell test lab. We come with idea to use the same principle of resonant machines for more widespread electrodynamics vibration machines (Shakers).

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3. Description of vibration machine

The basic principle of electrodynamics vibration machines is described in Fig.1.
The structure of an electrodynamics has some resemblance to a common loudspeaker but is more robust.

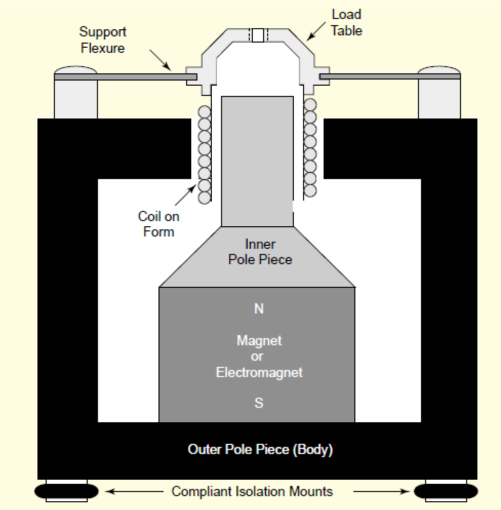
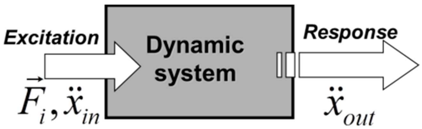


Fig. 1. Mechanical principle of electrodynamics shaker

If we define the simplest one mass system with one degree of freedom, we can describe the transfer function by equation (1) and simplified mechanical structure –see Fig.2.



$$A(f) = \frac{\ddot{x}_{out}(f)}{F(f)}, or \frac{\ddot{x}_{out}(f)}{\ddot{x}_{in}(f)} \qquad (1)$$

Fig. 2. Definition of transfer function for simple mechanical system

4. Fatigue testing on electrodynamic vibration machine

For some component, where to be compared fatigue life for different design, technology of connection or used material, is possible use for fatigue testing also electrodynamic vibration machine. For this approach we need to know character of loading during operating mode. In some cases can be useful to use FE model to correct understanding to stress distribution. Then is necessary to simplify fixing and find suitable resonant - eigen frequency such as generate the same mechanical loading of component as in operating mode. Very often is also possible use the additional mass for tuning the system to appropriate frequency of loading amplitude.

The simplified schema of test setup can be seen at Fig.3.

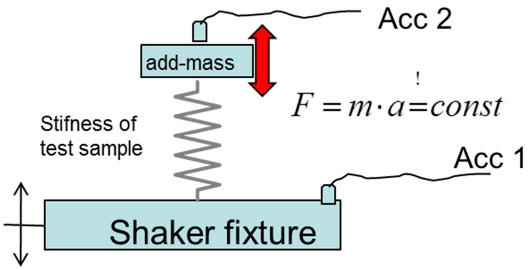


Fig. 3. Simplified schema of test setup

For the fatigue testing were used more control strategies:

4.1. White noise random excitation controlled to shaker fixture

Tested structure is excited by white noise random acceleration at the fixture. The frequency range should be set to cover the resonant frequency of tested samples. During the test is running the excitation of shaker fixture is hold constant. Response of additional mass is excited to resonance frequency. This method enables multiple sample testing. For each sample is necessary to monitor response of additional mass. As the groves the fatigue crack, the response falls down, but the white noise excitation cover whole range of resonance frequency to the damage. Then we can compare time to damage for all samples. Each sample has the same excitation.

Advantage: Multiple samples testing

Disadvantage: Not fully pure construction of Woehler curve.

4.2. Harmonic sine excitation controlled to acceleration to additional mass

Tested structure is excited by harmonic acceleration at the fixture and holding near the resonant frequency to achieve high levels of gain of additional mass. The whole system is controlled to constant amplitudes of acceleration on the additional mass, thus hold the constant inertia forces - which causes constant level of stress. Then is suitable hold structure at resonant frequency. As the fatigue crack grows, the stiffness decrease and thus also decrease resonant frequency. For appropriate control is necessary to use some software tool (Sine Resonance Track). The usage of this method can construct individual point of Woehler curve at constant level of loading.

Advantage: Constant level of loading – controlled to acceleration

Disadvantage: Only one simultaneously running sample

4.3. Harmonic sine excitation controlled to force induced to sample

The situation is same as for paragraph 4.2 with difference in control value. With some changes in design of testing fixture is possible use the dynamic force transducer instead of accelerometer. It gives us possibilities direct control the amplitude of load force. Whole structure is then controlled to force.

Advantage: Constant level of loading – controlled to amplitude of load force

Disadvantage: Only one simultaneously running sample

5. Experimental examples

On the next paragraphs there are shown examples and results from some realized tests. The same structure as in chapter 4 is used.

5.1. White noise random excitation controlled to shaker fixture

There was compared fatigue robustness of laser welding connections of shaft & valve. With aid of FE model were find the first bending eigen shape (see Fig. 5) which is close to real load operational mode.

For given test sample was designed test fixture for multiple testing (up to 4 samples)

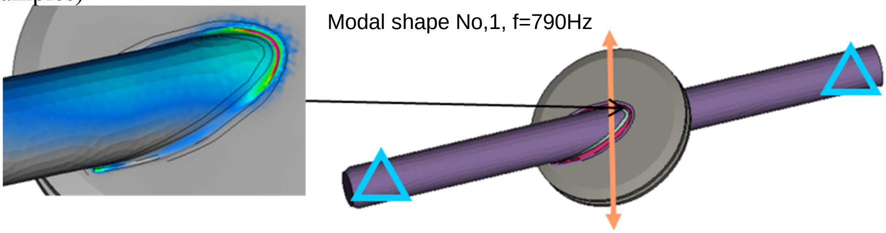
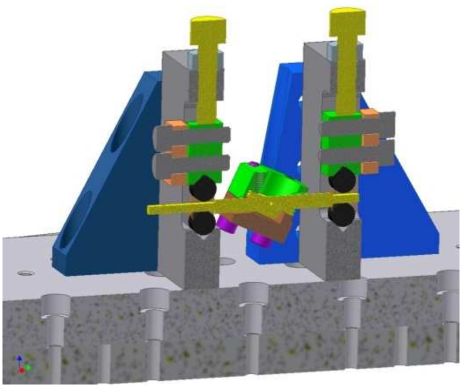


Fig. 4. Test sample with first bending eigen shape



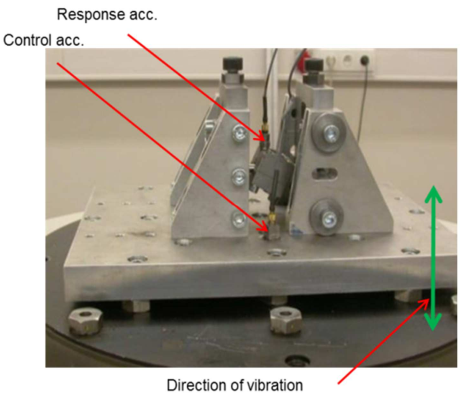


Fig. 5. Cross section of test fixing jig

Fig. 6. Test setup, control and response acc.

On the Fig.7 can be seen example of time response of test sample during running test. Used excitation: white noise random, level 15g RMS, with frequency range 100-850Hz

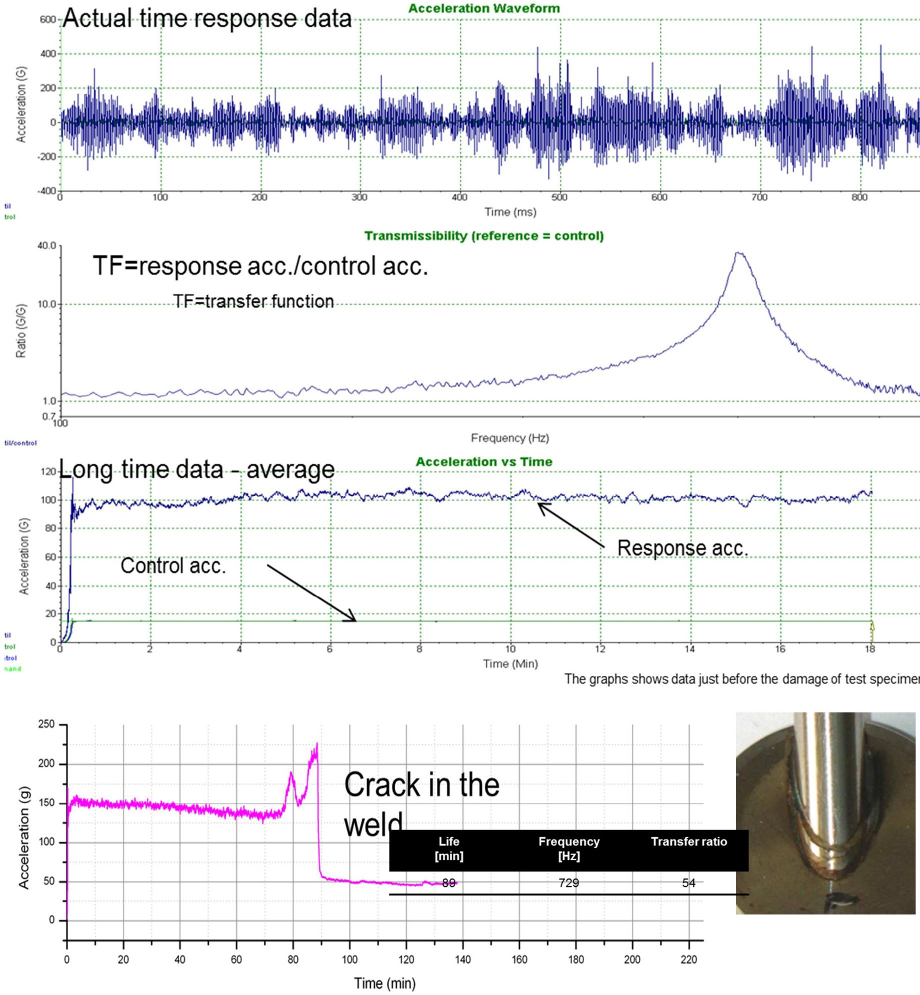
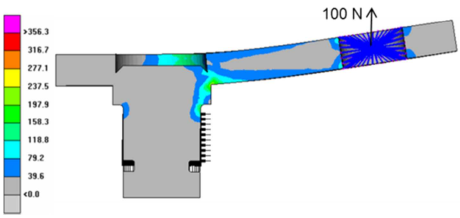


Fig. 7. Time response of excitation and response data, result of fatigue test, crack in sample

The result of test was time to damage for test samples which were loaded to same random excitation. Thanks this comparison was possible to select the robust technological solution for given laser weld. Testing was quite efficient due the 4 simultaneously running samples and typical time to damage around 60-90min (3milions cycles).

5.2. Harmonic sine excitation controlled to acceleration to additional mass

Similar as the previous example should this experiment also compare fatigue robustness of laser welding connection between pin and arm. Test sample is loaded in real field mostly by bending stresses. This was checked by FE simulations (Fig. 8)



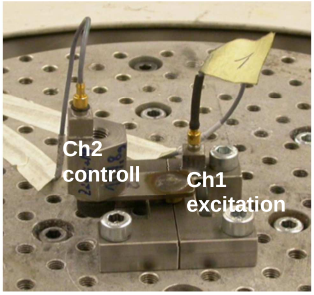


Fig. 8. FE simulation stress result of used loading by inertia force of additional mass, Test setup

On the Fig. 9 can be seen time response of whole 1 test sample until the connection is fully damaged. Typical parameters of test is follows: Initial resonant frequency 700Hz, time to damage 34min (1.25mil cycles)

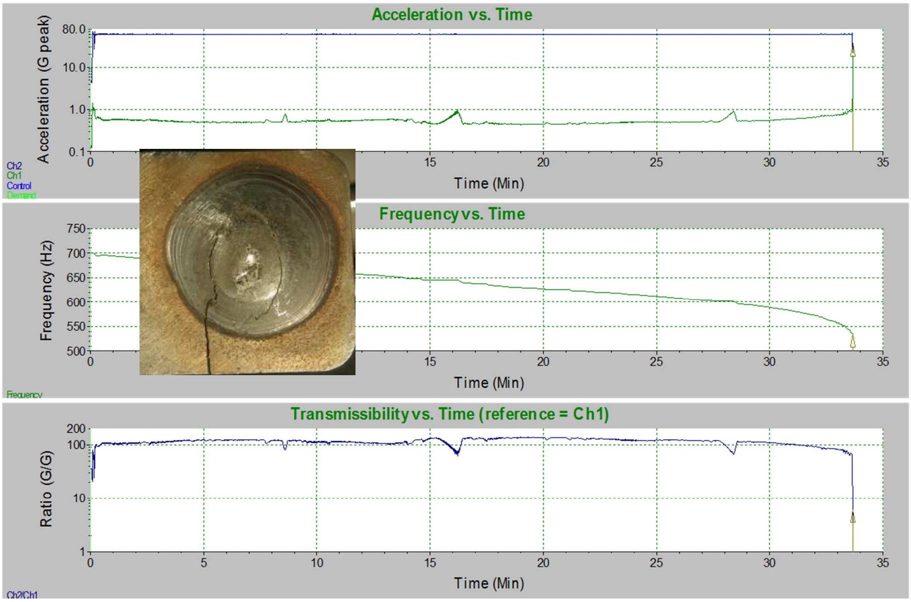


Fig. 9. Time response of whole test, Fatigue crack after the test

On the Fig.10 can be seen final Woehler curve for different technological solutions of laser weld connection.

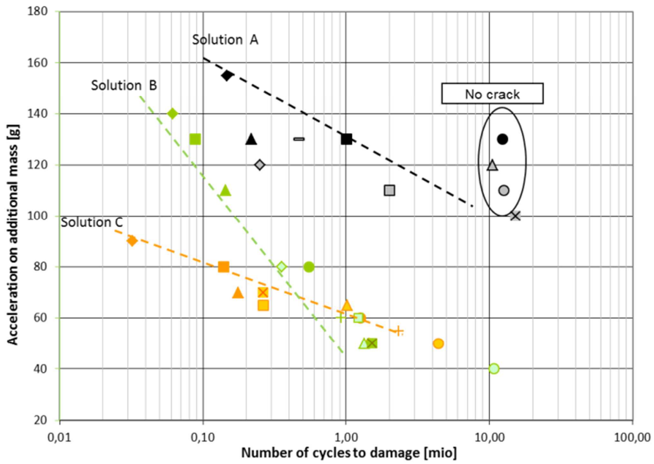


Fig. 10. Woehler curve for different solutions of welded connection

5.3. Harmonic sine excitation controlled to force induced to sample

This method is similar as previous, only the induced force was directly controlled by piezoelectric dynamic force transducer. The subject of test was overlapped laser weld of steel sheets. The shear loading was generating by additional mass connected via force transducer to test sample. The additional mass was fixed by linear bearing across fixing frame to the shaker body. Only vertical movement was enabled. Details can be seen on the Fig.11

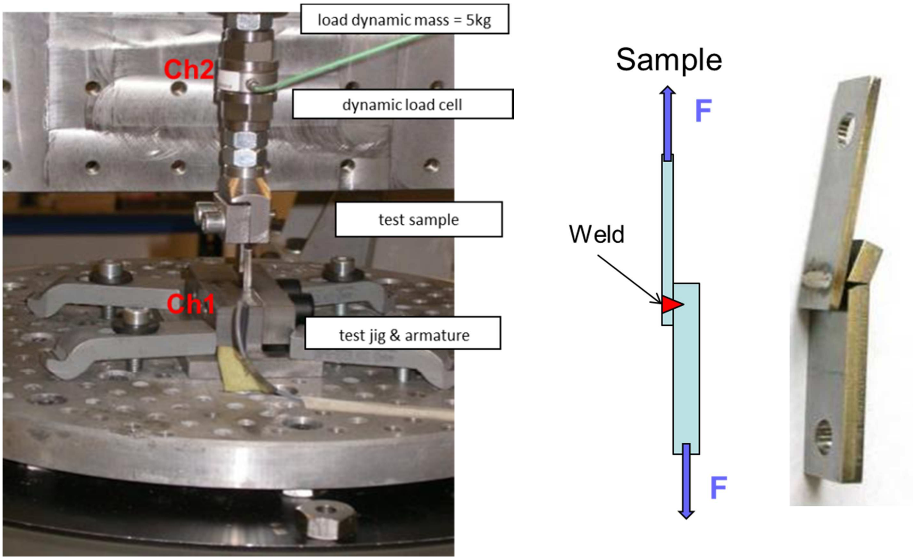


Fig. 11. Test setup on shaker, Test overlapped sample, Fatigue damage of sample

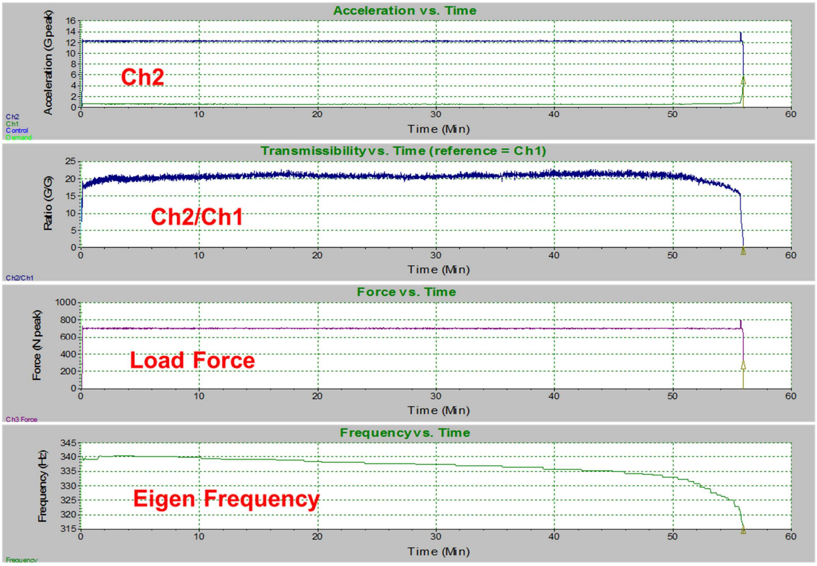


Fig. 12. Time response history of one test sample

6. Conclusion

There was described and experimentally verified method of a component fatigue testing with usage of generally available electrodynamic vibration machine. Next paragraph summarize the main feature of this method:

Advantages:

High time and energy efficiency of these fatigue tests, typical frequency 100-1000Hz

Usability for wide range of electrodynamic vibration systems

High variability of test method for different initial condition

Possible direct control of force and direct counting of load cycles

Suitable for component comparison test – fatigue robustness

Disadvantages:

Mostly for small samples, load forces in the range of few newtons up to 5-10kN

Mostly for alternate loading (without static prestress)¨

Only for samples with high rigidity- define the resonant frequency (not suitable for plastic, rubber)