

## **“A REVIEW OF FATIGUE TESTING MACHINES”**

By

**Galal S. A. Shawki**  
Professor and Dean  
Faculty of Engineering, Qatar University,  
Doha, Qatar - Arabian Gulf.

### **ABSTRACT**

In this paper fatigue testing facilities are first classified in accordance with a number of features which include purpose, type of loading, method of load application and transmittal as well as control system.

Owing to the significant role played by the loading system in defining the design features, scope and limitations of the testing machine, such systems are herein studied at some length.

Typical examples of test rigs built for uniaxial and multiaxial loading are presented.

### **1. INTRODUCTION**

The phenomenon of “premature” failures emanating from repeated stress was first noted in the railway industry in the 1840’s as railroad axles consistently failed at the shoulders [1]. The rounding of sharp corners did not obviate this type of failure which was termed “Fatigue” and earmarked to failure under repeated stresses.

The earliest systematic investigations into this phenomenon were conducted by August Wöhler (1819-1914) who displayed the results of his fatigue tests at the Paris Exhibition of 1867, which were also reviewed in the same year in “Engineering”, [2]. In 1870, Wöhler came to the conclusion that the stress range plays a most significant role in fatigue failures.

Wöhler was the first to introduce the concept of the so-called S-N diagram which relates applied Stress  $S$  to life, i.e. to number of cycles to failure  $N$ . He could thus show that the fatigue life decreases with higher stress amplitudes and that the material reaches a "Fatigue Limit" defined by the maximum stress that can be sustained by the material for an infinite number of stress reversals, usually denoted by  $S_{nr}$ . No wonder then that Wöhler is called the "Father of Systematic Fatigue Testing".

Wöhler's classical work was later expanded and substantiated by a number of researchers such as Bauschinger [3], Basquin [4], Griffith [5] and Gough [6] to name but a few.

Fatigue research has been conducted on a multitude of testing machines, the design varying in accordance with the nature and combination of load components, with the type of fatigue tested, e.g. high cycle, low cycle and thermal fatigue, with small scale or full size parts and structures etc., [7-25]. In the present study, it is intended to give a critical review of Fatigue Testing Machines so far developed, showing their salient design features, their potentials and their limitations.

## **2. CLASSIFICATION OF FATIGUE TESTING MACHINES**

Owing to the large variety of Fatigue Testing Machines developed, it is only feasible to point out the basic structural components of the machine before embarking on relevant classifications.

A fatigue test rig would be composed of the following components:

1. Load producing system which generates the cyclic load (or deformation),
2. Load transmitting members which act on test specimens,
3. Control device and shut off apparatus,
4. Counter for determining number of load cycles,
5. Measuring device (load, displacement, deflection, waveform, frequency etc.),
6. Frame of testing machine.

## **2.1 Classification Features**

Fatigue testing machines may be classified in a number of ways pending on the feature selected, e.g.:

1. Functional requirements or purpose of machine,
2. Type of load to be exerted on the test specimen,
3. Method of application of load,
4. Method of transmittal of load to test specimen,
5. Control system, viz. stress-control or strain-control versions.

Details of the most important classification criteria are given hereunder.

## **2.2 Classification in Accordance with Purpose**

1. General purpose testing machine,
2. Special purpose testing machine,
3. Testing machine for small-scale parts,
4. Testing machine for full-size structures and assemblies, [13,16].

## **2.3 Classification in Accordance with Type of Loading**

1. Axial loading (Push-Pull), [11,14,25],
2. Repeated bending,
3. Reversing (rotating) bending, [7,10,12],
4. Torsional loading,
5. Combined bending and torsion, [17,18,22],
6. Biaxial loading,
7. Multiaxial loading [15,20,21,23,28].

## **2.4 Classification of Methods of Load Application**

1. Spring forces and dead weights,
2. Centrifugal forces,
3. Hydraulic forces,
4. Pneumatic forces,
5. Thermal dilatation forces,
6. Electro-magnetic forces.

As the method of application of load plays a most significant role in the design, scope and limitations of the machine, typical examples for such methods are herein studied.

### 3. LOADING SYSTEMS

#### 3.1 Loading Systems Using Spring Forces and Dead Weights

Figure (1) shows an axial fatigue testing machine in which a fluctuating load is applied through a helical compression spring acted upon by a crank-piston mechanism. Owing to the linearity of the spring characteristic, the form of reciprocating motion imparted by the crank mechanism is transformed, in general, into fluctuating stress of constant amplitude.

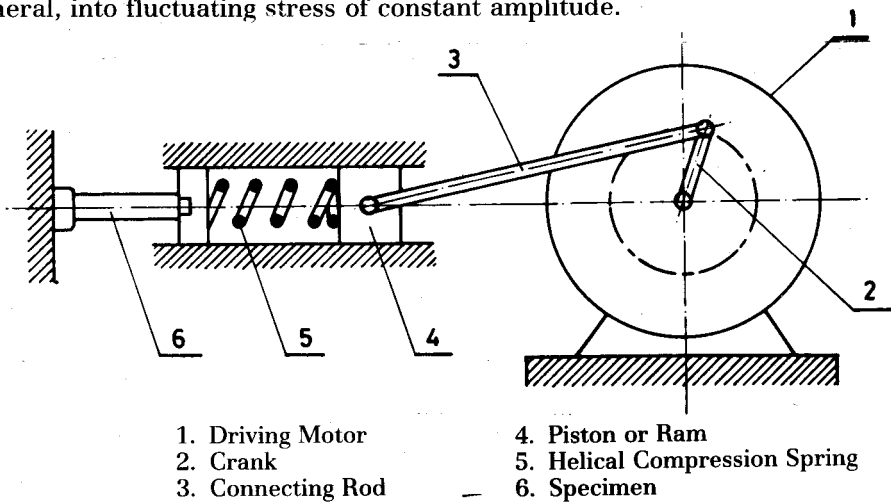
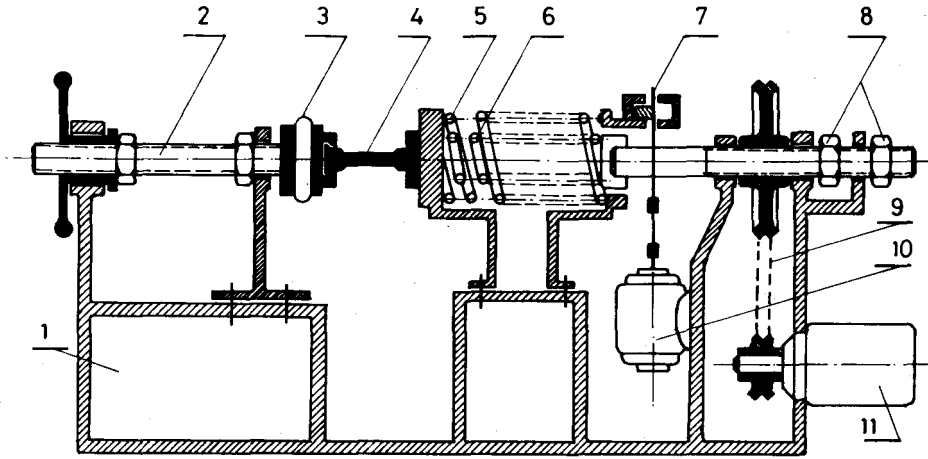


Figure 1: Schematic Arrangement of an Axial Fatigue Testing Machine with Constant Stress Amplitude.

In this category of loading systems the actuator can take the form of an out-of-balance exciter, Figure (2). This type of machine was used for testing railway carriage axles.

A variable-throw crank and connecting rod mechanism was introduced by Moore and Jasper [26].

Should the spring, in these machines, be omitted, and the reciprocating motion be applied directly to one end of the specimen, a strain-controlled system would evolve, provided that the testing machine and the dynamometer possess high stiffness in comparison with the test specimen [26].



- |                           |   |
|---------------------------|---|
| 1. Machine Base           | 7. Out of balance Exciter                 |
| 2. Adjusting Screw        | 8. Lock Nuts, Locked for High Speed Drive |
| 3. Dynamometer            | 9. Chain Drive                            |
| 4. Specimen               | 10. Exciter Motor for High Speed Drive    |
| 5. Dynamic Loading Spring | 11. Motor for Low Speed Drive             |
| 6. Static Loading Spring  |   |

**Figure 2: Constructional Arrangement of the Schenck-Erlinger Fatigue Testing Machine.**

The reciprocating motion may also be imposed on the load in the form of inertia forces [7]; this concept is applied in a machine at the National Physical Laboratory.

Owing to the fact that springs may not prove to be absolutely reliable due to temperature and inertia effects besides the possibility of overstressing, gravitational forces may well be resorted to. By rotating the test specimen under the action of a stationary weight suspended at the outer end of a lever, reversed axial load would be produced in the test specimen [10,26].

Resonant vibrations were produced, through mechanical means, by the so-called "slipping clutch" [27], in which the clutch was moved back and forth by a variable-throw crank, thus rubbing against a surface of the mass and exciting the system to vibrate at its natural frequency. The magnitude of the force transmitted to the specimen depends on the spring system and the throw of the driving crank.

### 3.2 Loading Systems Using Centrifugal Forces

Figure (3) shows the principle of producing a centrifugal force by means of an out-of-balance weight. Figure (4) exhibits a machine in which two pairs of weights rotating at the same speed produce a load along the axial direction. The load could be varied through a phase shift while the machine is in operation.

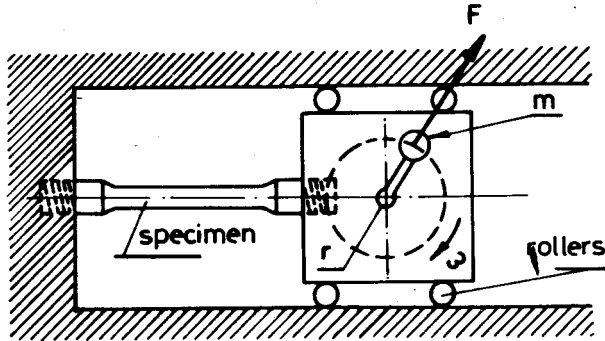
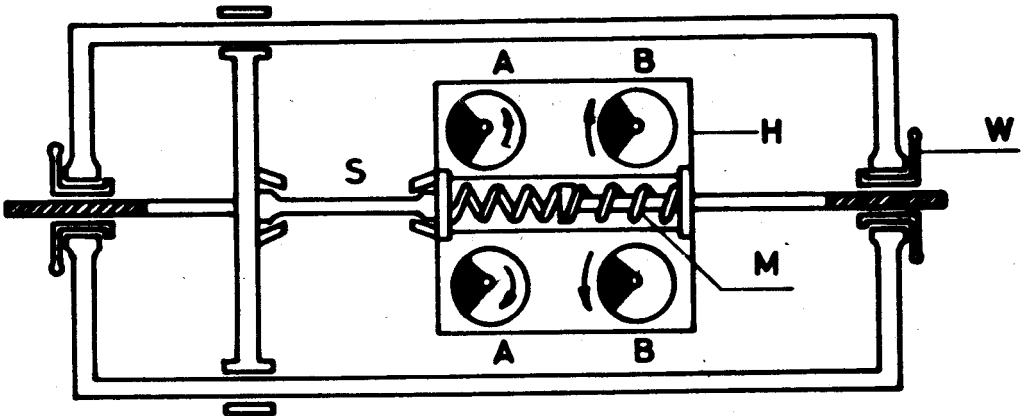


Figure 3: Oscillator - Type Fatigue Testing Machine.  
(Centrifugal Force  $F = mr\omega^2$ )



- A & B : Two pairs of unbalanced masses rotating in opposite directions.
- H : Housing of unbalanced masses
- W : Handwheel for application of static component of load
- M : Helical compression spring
- S : Test Specimen

Figure 4: Layout of the Schenck Tension - Compression Fatigue Testing Machine.

### 3.3 Loading Systems Using Hydraulic Forces

A typical layout of a fatigue testing machine composed of a single hydraulic cylinder is shown in Figure (5). In such machine very high loads (e.g. up to  $\pm 1$  MN or more) together with large amplitudes of dynamic load may be obtained. The early versions of this type of machines used hydraulic pulsators, [13].

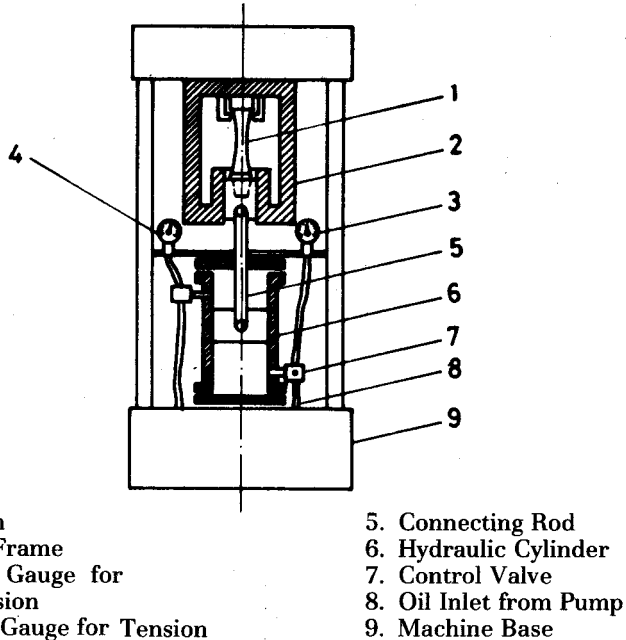


Figure 5: Fatigue Testing Machine using a Single Hydraulic Cylinder.

The problem of changing the load while the machine is in operation has been solved in different ways, namely:

1. By using a pump consisting of two identical pivoted cylinders, the angle between them being changed to control the volume of fluid fed to another cylinder connected in series with the specimen.
2. By using two cylinders in fixed positions, with the phase between them changed by means of a differential gear.
3. By changing the stroke of the pump piston.

An example of a fatigue testing machine using two hydraulic actuators is shown in Figure (6), [22]. The machine is capable of generating any combination of in-phase and out-of-phase bending and torsional loads. The two RAM computer-controlled hydraulic closed loop system provides independent control of each RAM. Signals for control and data processing are received from load cells and stroke transducers mounted in line with the hydraulic actuators.

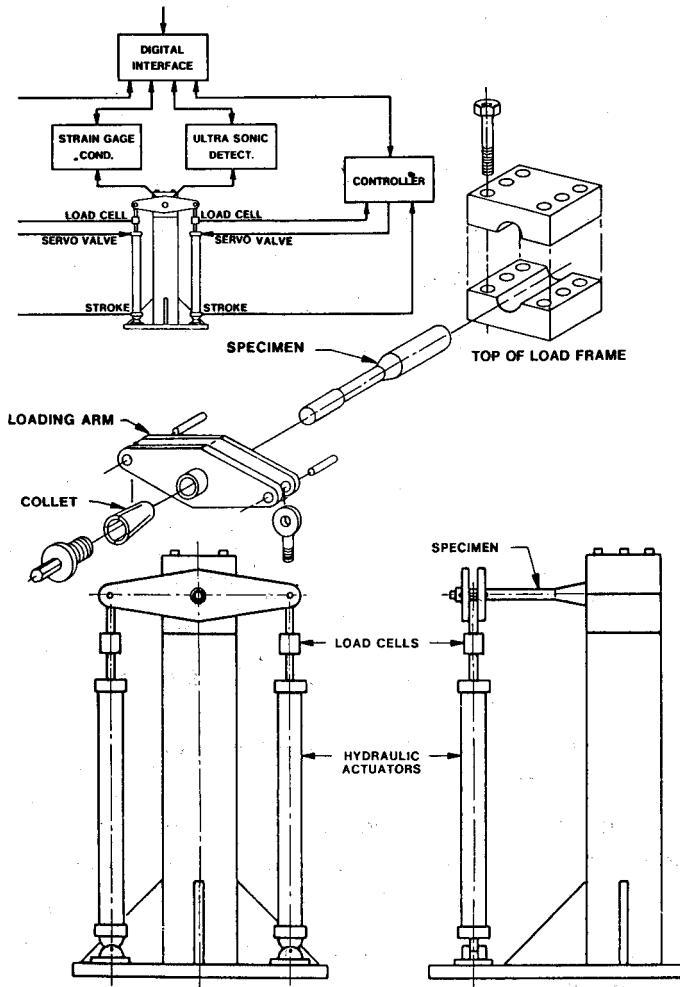


Figure 6: Bending - Torsion Fatigue Testing Machine showing Loading System and Instrumentation, [22].



A schematic layout of a testing machine capable of testing aircraft structures is produced in Figure (7), [16]. Specimens are loaded by means of a hydraulic jack fed from the same hydraulic line that feeds the wing loading jacks. Springs and lever systems are provided for applying compressive loads on specimens.

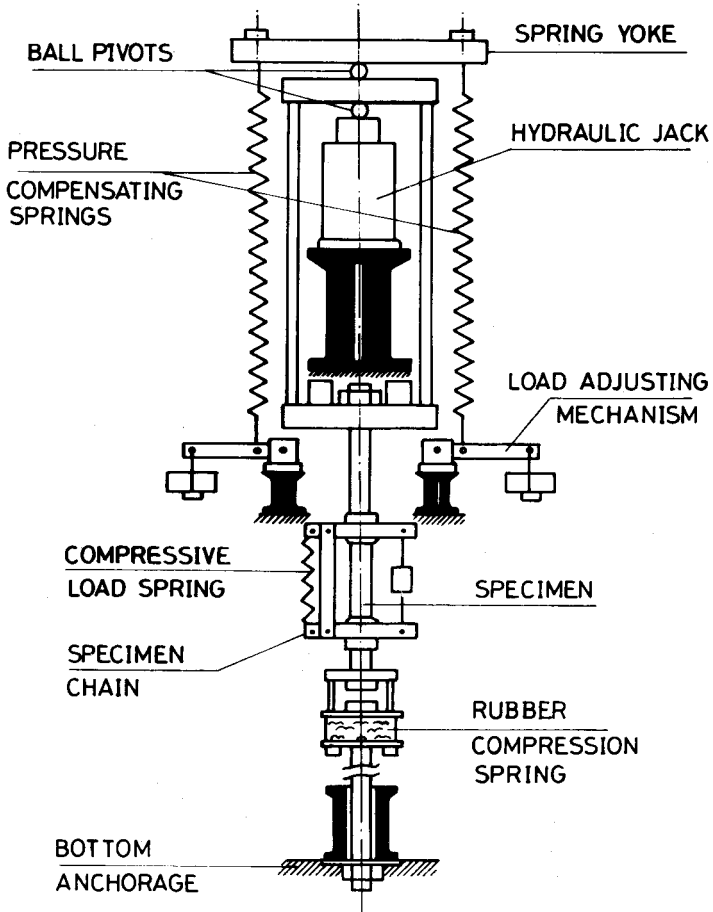
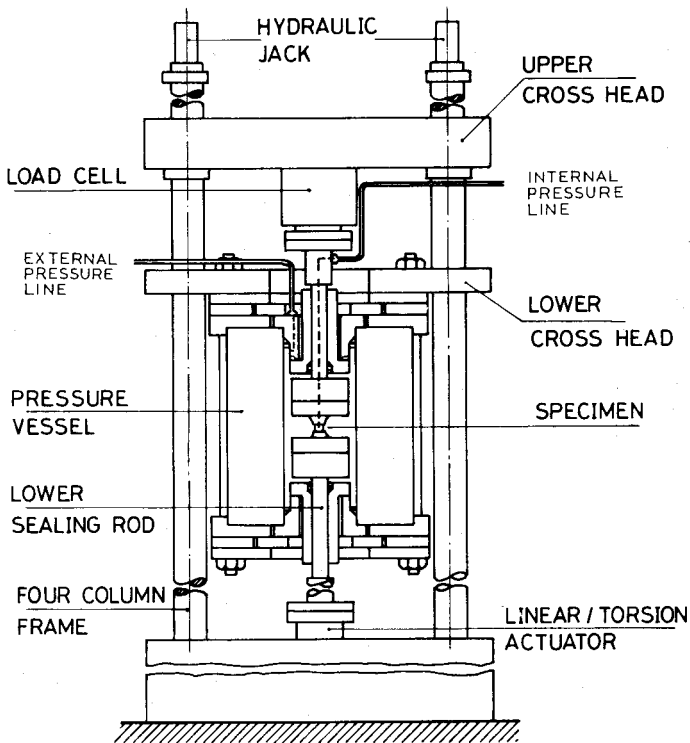


Figure 7: Fatigue Testing Machine for Cumulative Damage Investigations of Aircraft Structures.

Hydraulic fatigue testing machines suffer, in general, from a rather low frequency range of load application.

Besides fatigue behaviour obtained under monotonic loading, e.g. [7-14,16,19,25-27] and under combined bending and torsion, e.g. [17,18,22], further investigations have been run under multi-axial loading conditions, e.g. [15,20,21,23,28].

An example of a recent multi-axial testing machine is the facility displayed in Figure (8), [20,21]. This test rig is capable of straining a thin-walled tubular specimen in three independently controlled loading modes, viz. axial load (through hydraulic action), torsion and internal as well as external pressures.



**Figure 8: Layout of a Multi-Axial Fatigue Testing Machine, [22].**

The loading frame is a Schenck four column tension-torsion fatigue testing machine. The electronic control system incorporates load, strain and position control modes, these being controlled independently for any selected waveform.

### 3.4 Loading Systems Using Pneumatic Forces

A typical example of a pneumatically-operated fatigue test rig is displayed in Figure (9). Regulation of load is performed, while the machine is in operation, by changing the volume between the constant-stroke plunger and the cylinder attached to the specimen.

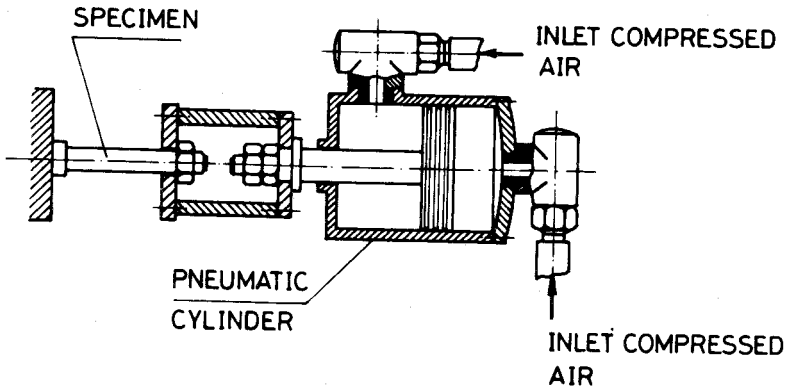


Figure 9: Pneumatically - Operated Fatigue Testing Machine.

### 3.5 Loading by Thermal Dilatation

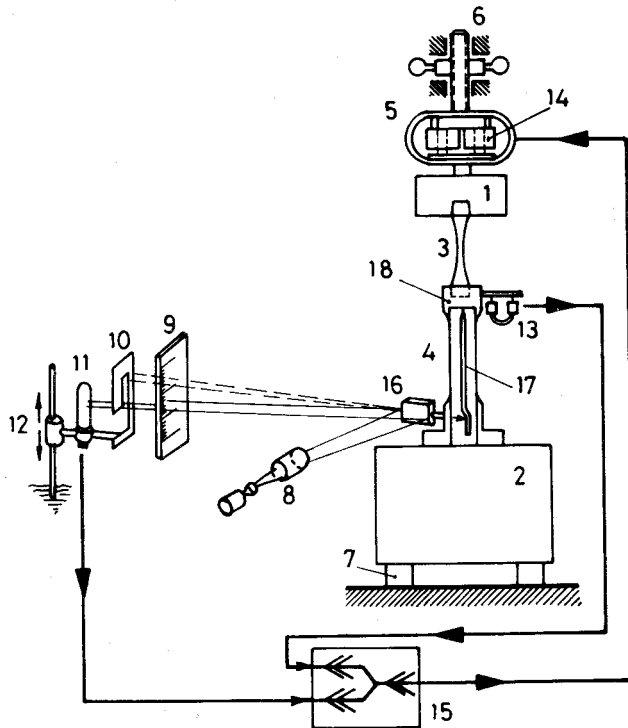
Cyclic strains may well be produced by heating and cooling columns in parallel with test specimen, the thermal expansion and contraction being controlled by thermo-couples fixed to each column. The cycling frequency would naturally be very low, e.g. two full cycles of strain per minute. Thermal stress fatigue lies, however, outside the scope of the present study.

### 3.6 Loading Systems Using Electro-magnetic Forces

Testing machines provided with electro-magnetic excitation possess the advantage of fatigue testing at very high frequencies. The first machine of this type, as built by Kapp [8], was made to run at a frequency of some 117 Hz.

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Figure (10) shows the schematic arrangement of a high frequency Vibrophore in which the frequency can be made to coincide with the natural frequency of the vibrating system by means of an amplifier which excites the machine, thus exciting reverberate control on the system. The natural frequency, which depends on the size and elasticity of the specimen as well as on the weight of the oscillating elements, can be changed within wide limits by the addition or removal of disc weights. The exerted force is measured by an optical dynamometer, a beam of light indicating, on a scale, both static and alternating load components. Load amplitude can be adjusted and kept constant by a photo-electric device controlled by the light beam of the dynamometer.



- |                      |                                   |                        |
|----------------------|-----------------------------------|------------------------|
| 1. Main moving mass  | 7. Vibration insulators           | 13. Impulse generator  |
| 2. Opposing mass     | 8. Optical projector              | 14. Driving magnet     |
| 3. Specimen          | 9. Dynamometer scale              | 15. Amplifier          |
| 4. Dynamometer       | 10. Diaphragm                     | 16. Oscillating mirror |
| 5. Pre-load spring   | 11. Photo-electric cell           | 17. Comparison strip   |
| 6. Adjusting spindle | 12. Slides of photo-electric cell | 18. Specimen holder    |

**Figure 10: Schematic Arrangement of the Vibrophore.**

#### 4. SUMMARY

A brief historical profile of the fatigue of metals is first presented and the basic components of a fatigue test rig are pointed out.

Testing machines are classified in accordance with purpose, type of load and method of load application. By virtue of being a factor of paramount importance in the design of fatigue testing machines, loading systems are herein critically reviewed. Such systems are based on the utilization of various types of forces such as spring, gravitational, centrifugal, hydraulic, pneumatic, thermal dilatation and electro-magnetic forces.

Schematic arrangements of typical fatigue testing facilities are displayed.

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