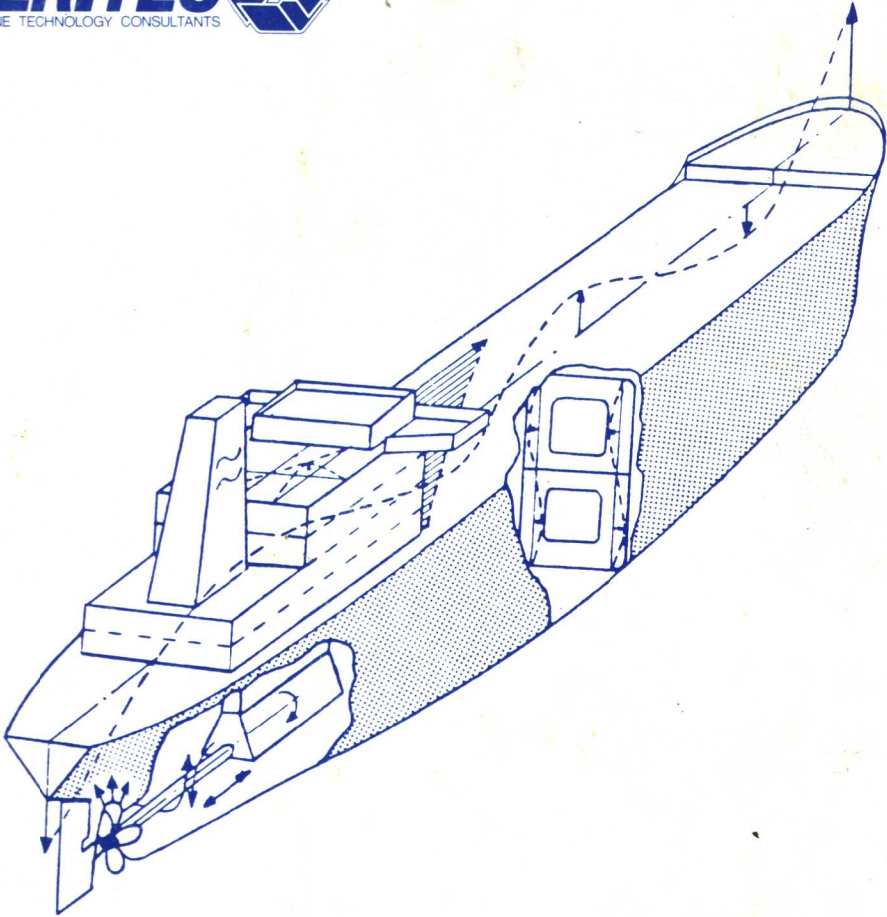


**VERITEC**  
MARINE TECHNOLOGY CONSULTANTS



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# **VIBRATION CONTROL IN SHIPS**

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## CHAPTER 6

## ELASTIC MOUNTING OF MACHINES AND EQUIPMENT

## Summary

In the analysis of the resilient mounting of machinery and equipment special attention should be paid to:

- System response; the installation will generally have 6 natural frequencies.
- Distribution of mass and mass moments of inertia.
- Characteristics and location of vibration isolators
- Stiffness of bedplates and seating.
- Flexibility of connections (pipework).
- Deflections due to torque reactions.
- Deflections during running up and slowing down.
- Alignment requirements. Shaft couplings.
- Equipment excitation forces. Unbalance etc.
- Impressed vibratory motion. Propeller, other machinery.
- Stability and loading of isolators from ship motion in the seaway.
- Facilities for inspection of resilient mountings/flexible connections.
- Reliability of installation in service.

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## 6. ELASTIC MOUNTING OF MACHINES AND EQUIPMENT

### 6.1 Introduction

In recent years an increasing proportion of items of equipment in ships is mounted resiliently. Depending on the circumstances the purpose may be:

- i) to reduce the vibration level in the ship as a whole (isolation of excitation source)
- ii) to prevent an existing level of vibration energy being transmitted in full to the item (equipment protection).

It should be noted that conflict between these goals often occurs; for instance when a number of machines and other equipment are installed in some small region of the ship's hull and exchange of vibration energy takes place.

Machinery and equipment which primarily come into consideration for resilient mounting are:

- Generating sets
- Diesel generator engine exhaust pipes
- Main Diesel engine exhaust pipes
- Compressors
- Pumps
- Piping from compressors and pumps
- Fans
- Air-conditioning machinery
- Hydraulic pumping units and pipe systems
- Gyro motor generators, instruments, etc.

Other machinery which has been resiliently mounted with satisfactory results is:

- Medium speed main Diesel engines
- Reduction gears for high speed Diesel engines (together with the engines)
- Steam turbines

Slow speed Diesel main engines do not readily lend themselves to elastic mounting since it is difficult to design a sufficiently resilient (and at the same time stable) mounting system for overcritical operation.

When elastic mounts are to be used the complete system (machinery/ equipment, mounts, foundation) must be thoroughly studied at the design stage. There are also further things to consider:

- i) alignment of the equipment whenever this is a requirement
- ii) relative movement of the equipment, due to ship motion in a seaway
- iii) sufficient flexibility of all pipes, ducts, cables, etc. connecting the equipment to the surroundings
- iv) access for maintenance and inspection
- v) when used for the purpose of reducing structure-borne noise, avoidance of short circuits in the acoustical path between equipment and surroundings.

A flexibly mounted machine unit acted upon by periodic forces and moments may be regarded as a general vibration source; the flow of vibrational energy into the foundation not only depends upon the actual forces and moments but also on the installation arrangement.

In general, a flexibly mounted machine, as for instance a compressor or a pump, has 6 degrees of freedom and thus possesses 6 natural frequencies,  $f_{n1}$ ,  $f_{n2}$ , ...,  $f_{n6}$ . (For more details on these matters see Appendix to this Chapter.) Now, if any excitation frequency coincides with a natural frequency of the system a state of resonance will exist, leading to greatly increased movement of the body. Under such conditions large forces will be transmitted to the foundation; continuous running at resonance is therefore to be avoided. Running up to normal operating speed from standstill, a process during which the excitation frequency will "hit" all the natural frequencies at subsequent instances, should be done as fast as possible.

#### 6.1.1 Natural frequencies

The natural frequencies for any contemplated elastic installation can be determined once the following data are given:

- i) Inertia distribution, i.e. the centre of gravity location, the total mass and the mass moments and mass products of inertia for all components belonging to the system.

- ii) The dynamic spring stiffness in the 3 principal directions for all elastic mounts.
- iii) The location of all the elastic mounts relative to a set of coordinate axes fixed to the system.

It is usually satisfactory to neglect dissipation effects and consider that the system is conservative. This implies that at any time  $t$ ,

$T + V = \text{constant}$  for the freely vibrating system

where

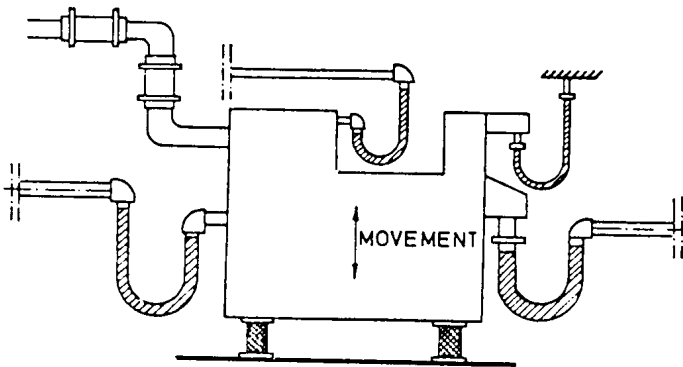
$T$  = kinetic energy  
 $V$  = potential energy

A general approach for deriving natural frequencies is outlined in Appendix A.6.

## 6.2 Design Considerations

### 6.2.1 Pipe connections

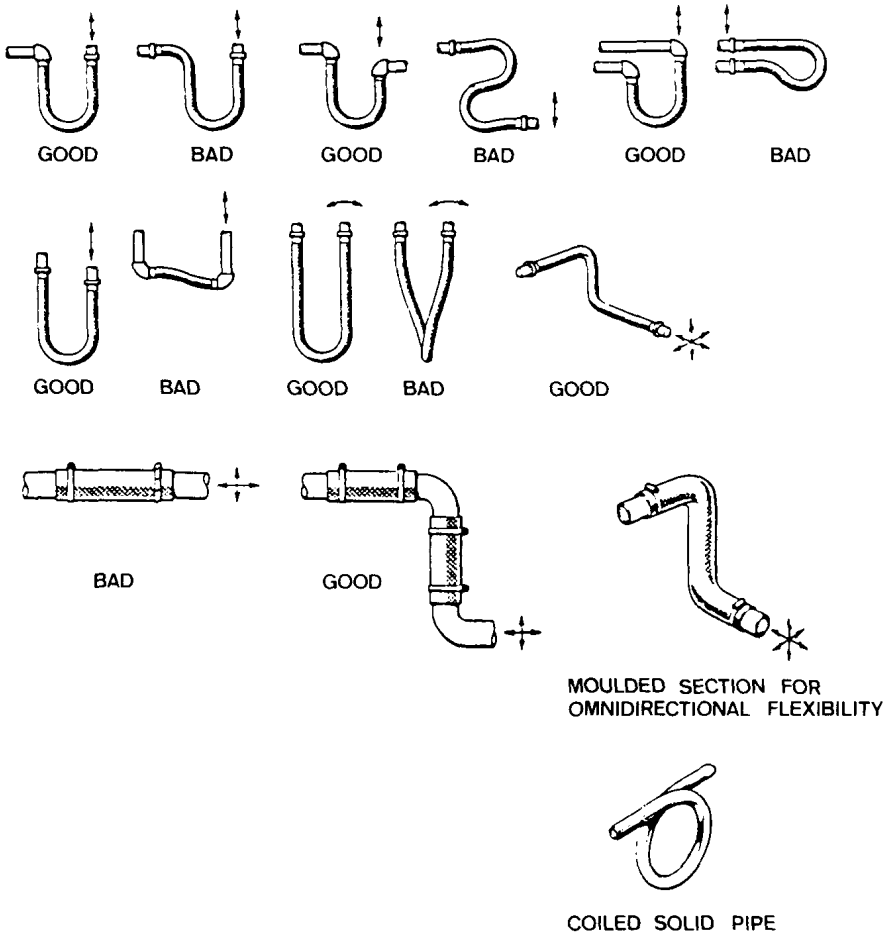
All pipework which is connected to flexibly mounted machinery must be able to absorb a certain amount of movement without damage. At the same time, the connections must be arranged in such a way that they do not act like stays and prevent movement of the machinery. Fig. 6.1 depicts a satisfactory pipe arrangement.



A SATISFACTORY WAY OF CONNECTING PIPE-WORK TO AN ELASTICALLY SUPPORTED ITEM.

Fig. 6.1

The ends of hoses should not be subjected to large bending loads. Flexible hoses are relatively stiff and should be so arranged that twisting motions are avoided, see Fig. 6.2.



ARRANGEMENTS OF HOSE CONNECTIONS.

Fig. 6.2

Where possible, pipes should be supported in suitable sound isolation material (fire, temperature requirements, etc.) in order to reduce the transmission of structure-borne sound, see Fig. 6.3. A resilient bulkhead transition is shown in Fig. 6.4.

Pipes directly clamped to frames, decks or bulkheads give rise to acoustical short-circuits.

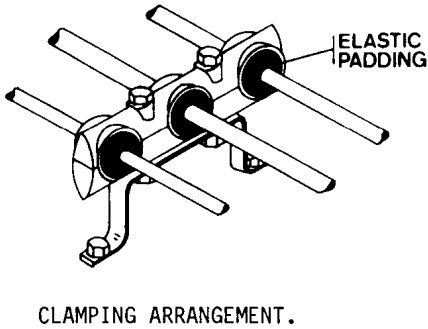
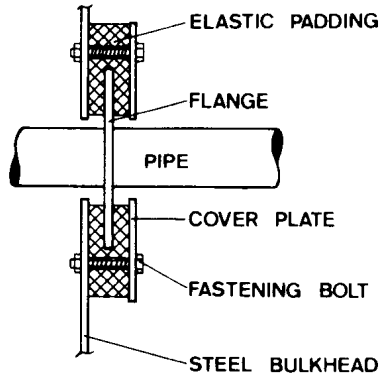


Fig. 6.3



BULKHEAD TRANSITION.

Fig. 6.4

Main engine and auxiliary engine exhaust pipes should be supported resiliently. The layout should be checked by calculation to ensure that it does not become resonant at slow, half or full speed with excitation from the propeller, the free forces and moments of the engines or the exhaust gas impulses. The pipes must be supported and stayed in such a way that their movement in bad weather does not overload the resilient mounting arrangements.

#### 6.2.2 Shaft couplings

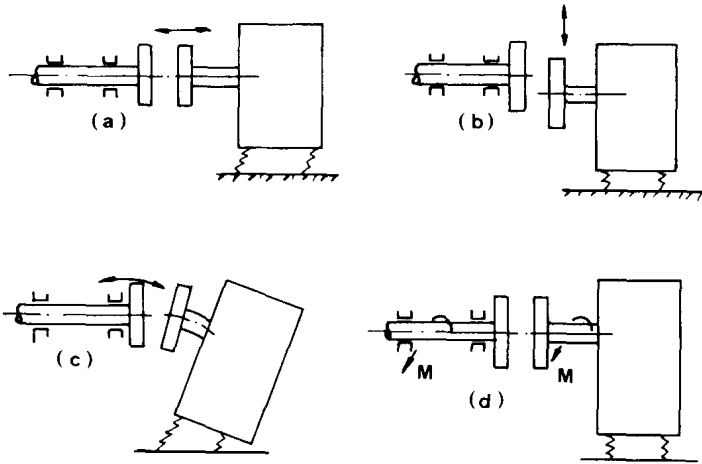
A shaft coupling must be evaluated from considerations of the dynamic response of the shaft system.

- torque variations
- torsional vibration
- axial vibration
- whirling.

It must also be designed to function under permanent misalignment conditions often occurring in practice, and stand up to transient loads during start and stop periods.

When the output shaft from a resiliently mounted machinery unit has to be connected to another shaft supported in comparatively stiff bearings, the connection must be flexible, so as to allow, see Fig. 6.5:

- i) Relative axial displacement.
- ii) Relative lateral displacement.
- iii) Relative angular displacement.
- iv) The maximum torque transmitted.



REQUIREMENTS FOR FLEXIBLE COUPLINGS.

Fig. 6.5

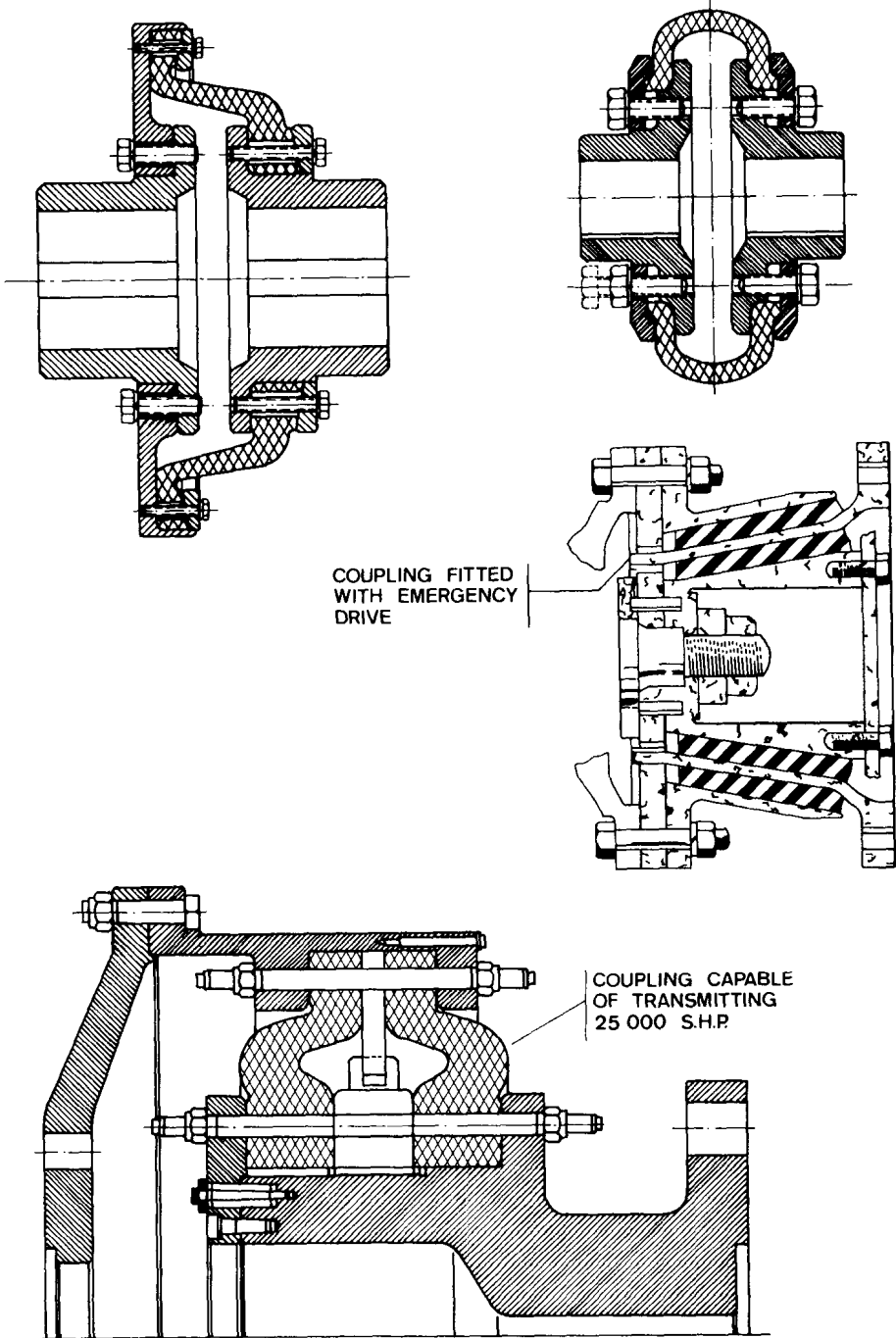
Common types of flexible couplings are shown in Fig. 6.6, a rubber compound or layers of fabric bonded with rubber provide the required flexibility.

All-metal flexible couplings are illustrated in Fig. 6.7.

A common (and usually satisfactory) arrangement is to fit two flexible couplings in series, see Figs. 6.8 and 6.9.

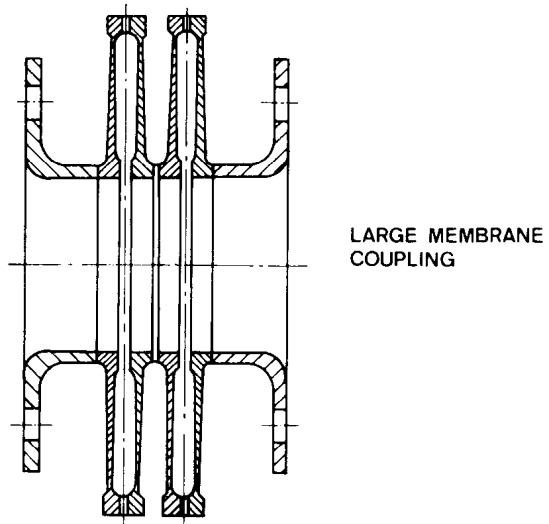
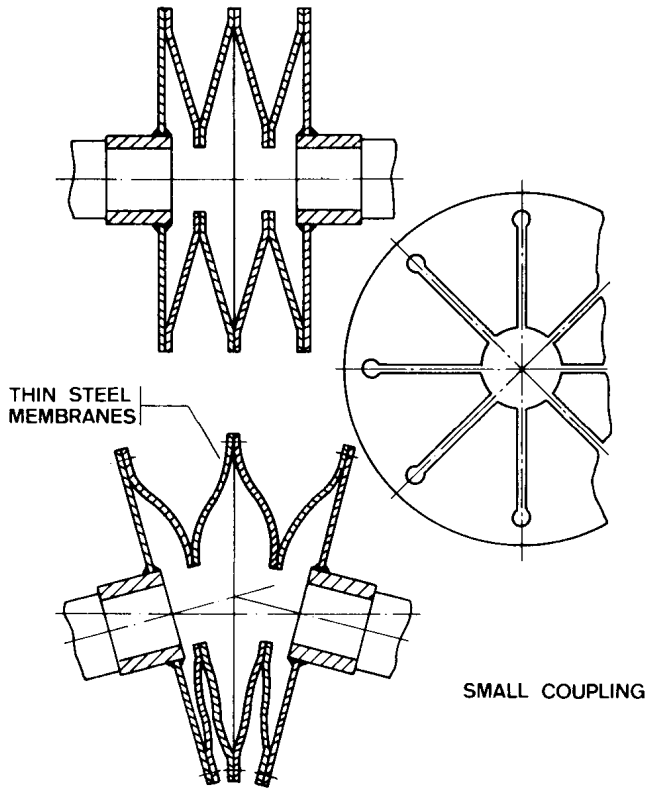
A third variant is the cardan shaft, well suited even to high power outputs and applicable to about 6 000 R.P.M.

An example of a recently designed elastic installation of a ferry's main engine is depicted in Fig. 6.10. Engine and gearbox are solidly mounted to a stiff subframe which in turn is erected on six resilient mounts. Low levels of vibration and noise were achieved.



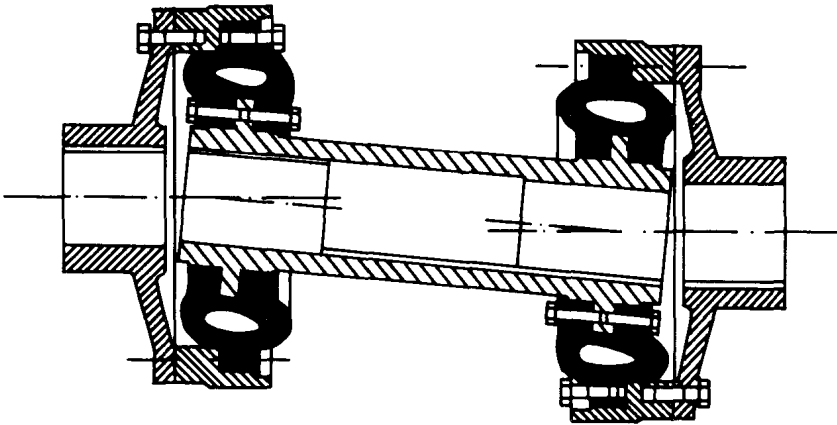
FLEXIBLE COUPLINGS OF TYPICAL DESIGN.

Fig. 6.6



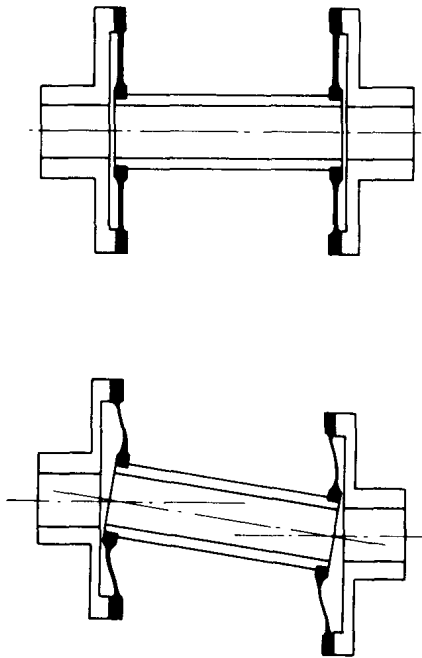
ALL-METAL FLEXIBLE COUPLINGS.

Fig. 6.7



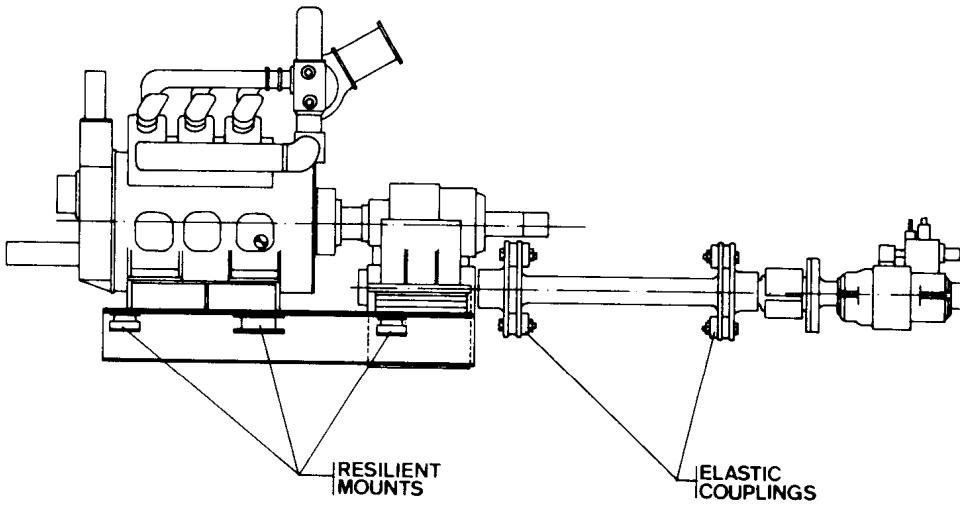
TWO COUPLINGS IN SERIES. RUBBER AS THE FLEXIBLE COMPONENTS; NOT TORSIONALLY STIFF.

Fig. 6.8



TWO COUPLINGS IN SERIES. THIN STEEL DIAPHRAGMS AS THE FLEXIBLE COMPONENTS; TORSIONALLY STIFF.

Fig. 6.9



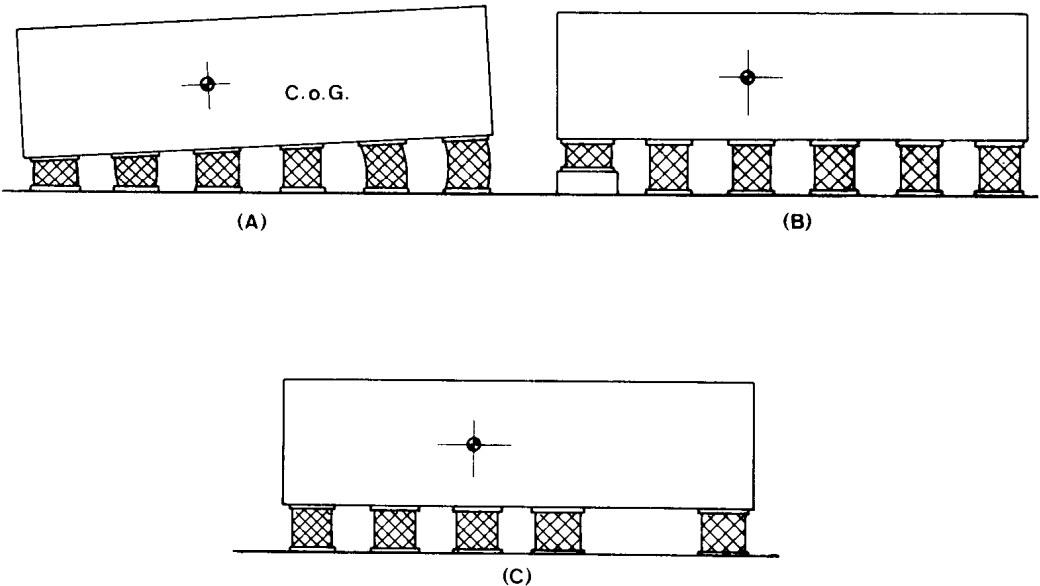
LAYOUT OF ENGINE/GEARBOX/SHAFTING FOR A FERRY'S PROPULSION MACHINERY.

Fig. 6.10

### 6.2.3 Other considerations

It should be ensured that flexible pipes and connections do not impose other loads on the equipment than those expected to be catered for, i.e. the fraction of their weight designed to be supported by the equipment. Pipes should not be strained in order to mate joints.

The load distribution for the mounts supporting an item of equipment should be such that no mount is excessively stressed. An uneven load distribution is often a result of wrong estimation of the location of the equipment's centre of gravity, resulting in an attitude depicted in Fig. 6.11(a). The left-hand mounts may be overloaded to such an extent that their performance and endurance are greatly lowered, whereas the right-hand ones may be hardly loaded at all. The system, probably assumed to have two planes of vibration symmetry (see Section 6.7.3) in this particular example, will in fact only have one: other frequencies than those estimated by calculations will show up. Attempts to effect a cure by choking up individual mounts, see Fig. 6.11(b), will not solve the problem. Removal of a pair of mounts may, however, be a practical way to bring about the correct alignment, see Fig. 6.11(c). The remaining mounts will have to carry a somewhat higher load, but if designed on the conservative side this should not be detrimental.



WRONG ESTIMATE OF C.o.G. LOCATION.

Fig. 6.11