11. MOUNTING SYSTEM

CONTENTS

MOUNTING SYSTEM

1. GENERAL

When setting an engine on a machine, major importance should be given to assembling with precision the parts connected to flywheels, and crank shafts which rotate at high speeds.
The following points must be carefully observed.

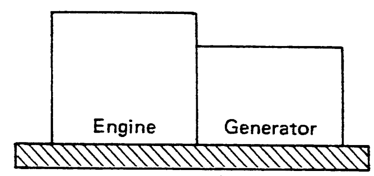
1) Do not apply excessive force to the engine during assembly. (For prevention of off-centering surface deflection, excessive, clearance and thrust)
2) Minimize bending moment to rotating shaft. (For extended life of shafts and bearings)
3) Avoid resonance around the engine mounting frame. (Use of appropriate supporting method and rigid mounting frame).
4) Avoid torsional vibration between the engine and driven components. (Connection with a rotating body)
5) Take air flow into consideration when enclosed cover is used. (for proper cooling)
6) Provide access for easy maintenance when covering engine or parts. (for easy maintenance)
7) Take maintenance and reliability into consideration for remote control. (for positive operation)

2. SUPPORTING METHOD

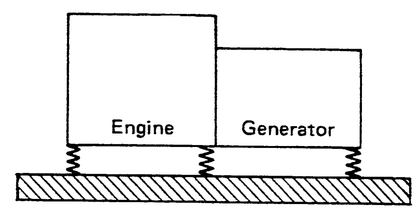
Vibrations from a machine mounted with an engine depend on the vibration of the engine itself, rigidity of the mounting frame, weight of engine with equipment connected, vibromotive force and the supporting method between the engine and equipment.
Improper mounting and support will create resonant vibration in the engine system, which will cause noise and can result in major problems. The supporting method must be carefully designed.

Typical connection and supporting methods

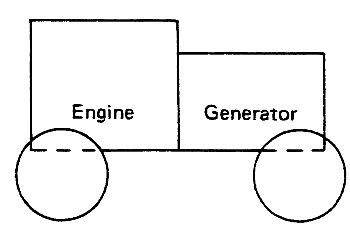
1) Direct-connection, stationary



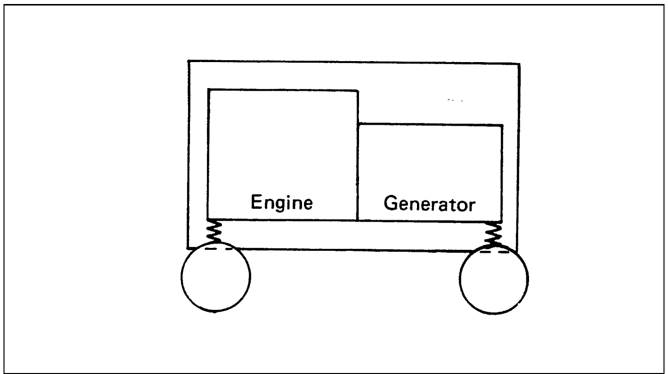
2) Direct-connection, anti-vibration support



3) Direct-connection, movable (tire)



4) Direct-connection, anti-vibration support, movable



5) Separate transmission, anti-vibration engine support

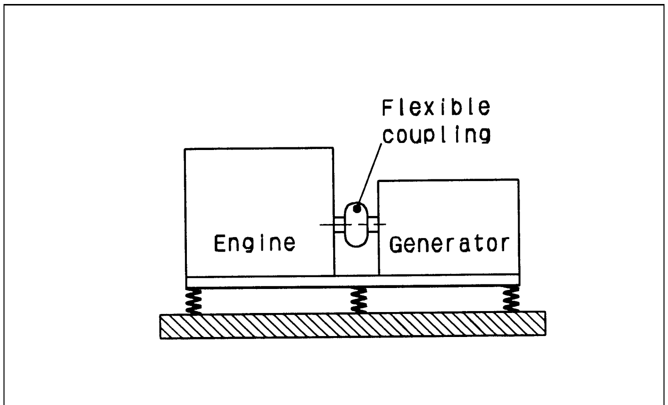


Fig. 11-1

Determine the best supporting method considering the above vibration conditions and the characteristics of the machine on which the engine is to be mounted.
Vibration acceleration and amplitude should be below the allowable levels.
Many types of anti-vibration support are being adopted recently.

Explain the determination method of anti-vibration support specifications next.

What is the goal for engine mounting ?

a) If machine has an operator and noise / vibration reduction are very important, then maximum vibration isolation is required.
However, this usually means that the isolators are very "soft" and have larger movement, so any accessory attached to the engine should have their "mass" as closely centralized to the engines / transmissions natural "roll center" as possible or very high displacement, acceleration type vibration can occur.
e.g. : The further away from engine / transmissions natural "roll" center the end of the muffler gets, the worse the movement.

b) If no operator, (e.g. : water pump) then isolation importance is not as great and "hard" mounts with less movement can be used.
This will make it much easier to mount the engines accessories to the engine (less "wobble").
However a high frequency, high acceleration, low displacement vibration can occur.

c) Is machine subjected to heavy bouncing ?
Either moving by itself or when being carried by another vehicle.
Mounts that may have to withstand up to 6G (6X) engine transmission weight may be required with strong overload in the vertical +/- and lateral movements.

d) Is mounting base rigid enough ?
That the base does not have an interfering natural frequency / displacement that coincides with the engine / attachment / transmission isolators and engine rotational frequency.

This is when a vibration reading on the machines chassis is important and may require the use of a strobe to point to the problem area.

[REQUIREMENTS IN MOUNTING THE ENGINE]

- Keep the chassis isolated from engine vibration as much as possible.
- Support the engine with the operating condition safely.

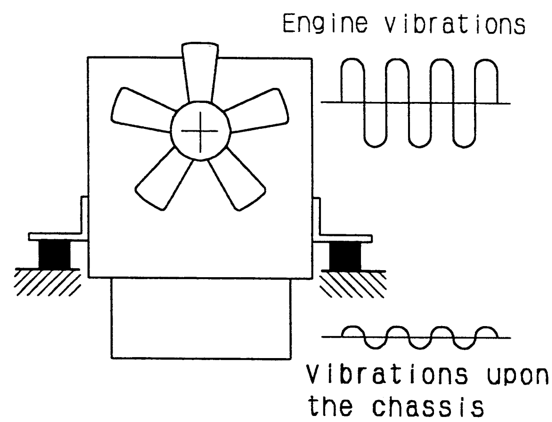


Fig. 11-2 Engine mount

(1) How to isolate the chassis from engine vibration

Elastic materials such as vibration-insulating rubber products (VIRP) are used to support an engine mount to isolate the chassis from engine vibration as much as possible.
A flexible supported engine mount has its specific natural frequency.When the engine runs near or at rpm that corresponds to that frequency, resonance occurs, which adversely amplifies the vibratons. To cope with this problem, the following points are important. :
First, support the engine with an elastic material such as VIRP.
Second, keep the engine mount's natural frequency away enough from the engine's operating speed range. (See Fig. 11-2)
Vibration-insulating rubber products (VIRP), commonly used for engine mounts, are discussed.

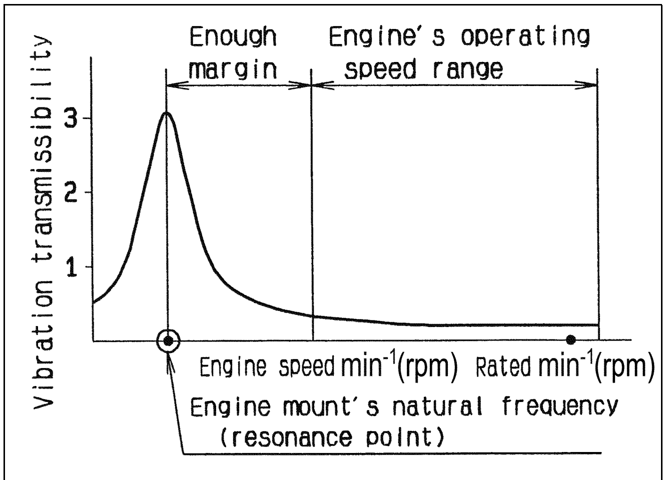


Fig. 11-3 Engine's operating speed range versus engine mount's natural frequency

(2) Conditions for safety supporting with vibration-insulating rubber products (VIRP)

Unlike rigid support with metallic stays, stiffness is a key factor in supporting an engine with VIRP in an elastic way. The VIRP helps reduce the effect of vibration upon the chassis, but the engine tends to shake more.
The softer the rubber is, the smaller the vibration transmissibility becomes, and the lower the resonance point drops. If a strong external force comes from the chassis, however, the engine will move, possibly causing an interference around the radiator or damaging the engine-related equipment. Keep engine mounting base very rigid. If the VIRP, with the rubber's deflection too large, easily gets cracked. For reliable engine mounting, therefore, keep the following point in mind :
Select VIRP that has small deflection with respect to various loads and that is durable enough.
Here are major loads that are exerted on an engine-mounting VIRP.

- Engine's own weight
- Engine's vibromotive force
- External force coming from the chassis

A VIRP to be applied must have a spring constant appropriate to support all these loads.
Now let's discuss some precautions on the loads in mounting an engine.

1) Engine's own weight

An engine's own weight cannot be avoided. Suppose that a load is equally applied on each piece of VIRP. Divide the engine's weight by the number of the VIRP pieces. The result must be below the permissible load of each VIRP piece. When the deflection of the VIRP is high, it is advisable to have a somewhat higher spring constant even within the permissible load. The permissible load P and the deflection H of VIRP are expressed as follow :

Permissible load of VIRP : $P > W/n$
Deflection of VIRP : $H = W / (K \times n)$

Where W : Engine weight
K : Spring constant of VIRP
n : Number of VIRP pieces

It is clear that the engine weight divided by the VIRP pieces must be smaller than the permissible load and that the deflection H must be kept low.

2) Engine's vibromotive force

The VIRP is exposed to the vibromotive force of an engine while it is running. An appropriately selected spring constant does not give the VIRP much deflection due to the vibromotive force. It should be noted, however, that generally there is a resonance point in the operating speed range of a rubber-mounted engine.
By resonance, the vibromotive force becomes multiplied by several times, which deflects the VIRP greatly. To allow no resonance point in the engine's operating speed range, the natural frequency must be kept out of this range.
Often, the engines low idle speed will have to be increased.
But when the engine STARTS and STOPS, the resonance point is experienced along the way of speeding up and slowing down.
The VIRP must withstand such vibrations that occur during the start and stop the engine.
These vibrations generally roll the engine. To reduce the deflection in such direction, increase the spring constant in the rolling direction or modify the support structure.

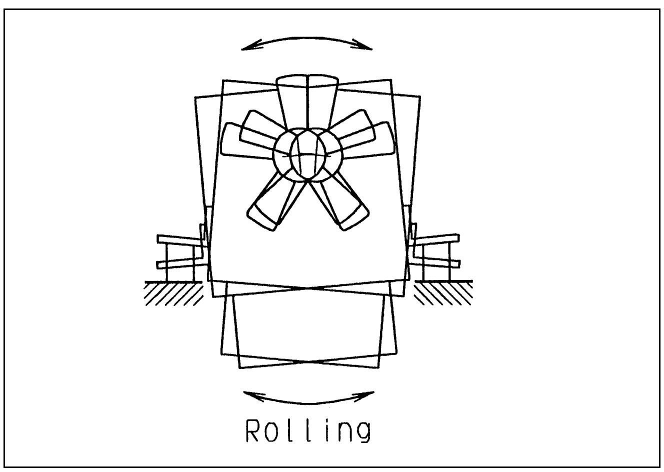


Fig. 11-4 Vibration at engine start and stop

3) External force coming from the chassis

On general purpose engines, an external force coming from the chassis is imposed mostly on the external force varies from machine to machine.
The VIRP must be strong and durable against the external force of the type of machine in question.
But the VIRP is not designed to withstand an impact load or other momentary force.
To deal with such force, it is absolutely necessary to add safety stoppers.

The stoppers can limit the VIRP's maximum deflection that is caused by the external force.
Any external forces beyond the limit are received by the stoppers, which protects the VIRP and ensures safeness.
If by any chance the VIRP breaks down, the stoppers work to hold the engine in place.
It is preferable to install the stoppers in 3 directions (vertical, crosswise and lengthwise).
Fig. 11-5 shows a typical stopper and Table 1 lists external forces that are transmitted from the chassis of various type machines.

Types of machines	External force
Stationary type	1 ~ 2G
Power unit type	2 ~ 3G
Offroad, frame and construction machinery	2 ~ 4G

Impact loads are not included in the above external forces.
Table 1 External forces that are transmitted the chassis of various types of machines

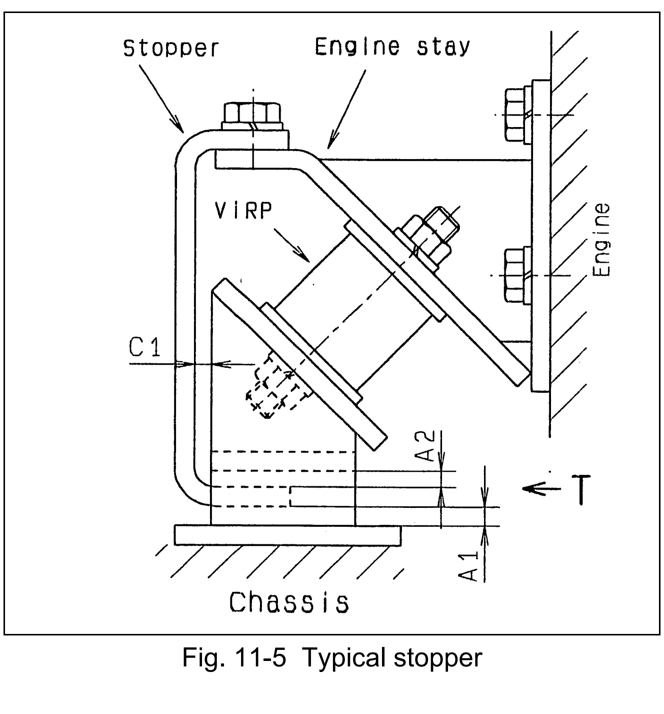
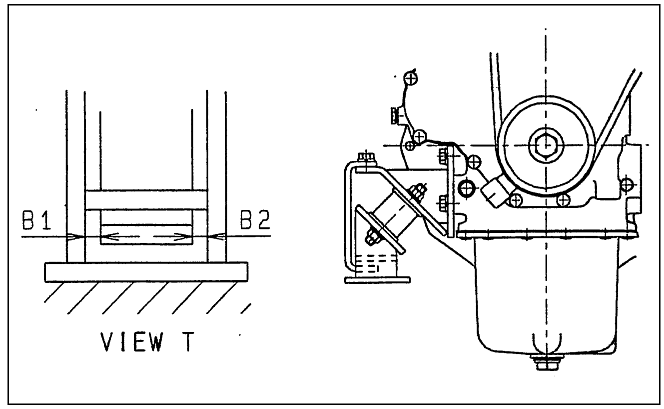


Fig. 11-5 Typical stopper



VIRP's vertical maximum deflection is limited by the clearance A1 and A2.
VIRP's lengthwise maximum deflection is limited by the clearance B1 and B2.
VIRP's crosswise maximum deflection is limited by the clearance C1 and C2.
(Clearance C2 is opposite clearance C1 with respect to the crankshaft center.)

[ENGINE'S VIBRATION CHARACTERISTICS]

Reciprocating engine structurally have their source of vibration inside (reciprocating movements of the piston and connecting rod, torque variations, etc.) Their frequency characteristics depend on the number of cylinders, cylinder arrangement and other factors. An engine's motion can be divided into 6 types : 3 translational motions (vertical, crosswise and lengthwise) and 3 rotary motions (rolling, yawing and pitching.) (See Fig. 11-6)
Below discussed are the relations between these 6 types of vibrating motions and the vibration characteristics of 4-cycle in-line 3 cylinders as well 4 cylinders engines.

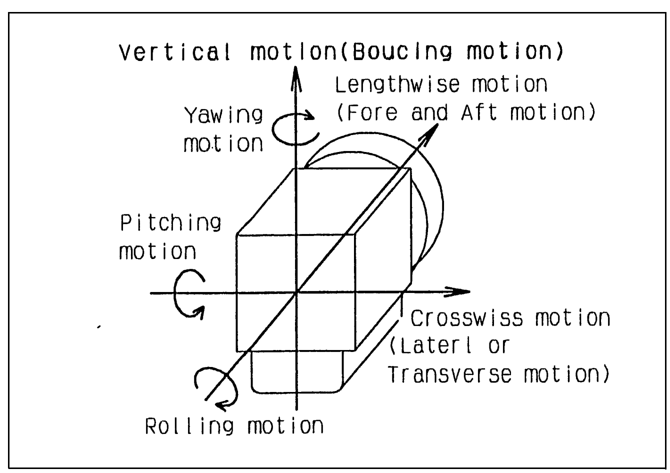
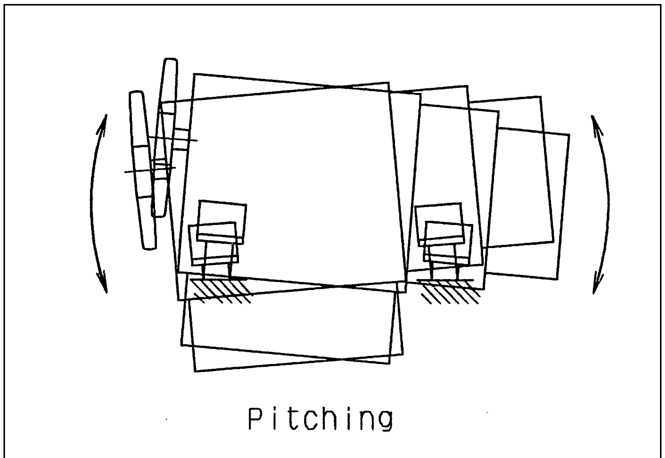


Fig. 11-6 Engine's 6 types of vibrating motions

(1) Three-cylinder engine's vibration characteristics

Engine's motion	Pitching and yawing
Rotational degree	1st order
Remarks	Caused by inertial couple of force. Aggravated with increasing rpm.
Engine's motion	Rolling
Rotational degree	One and a half order
Remarks	Caused by torque variations.



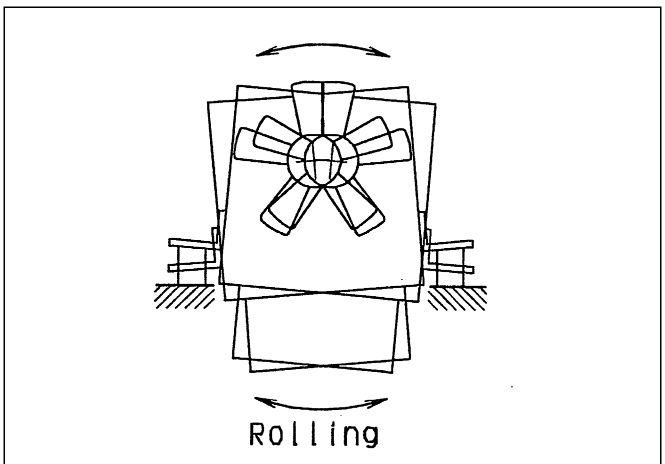
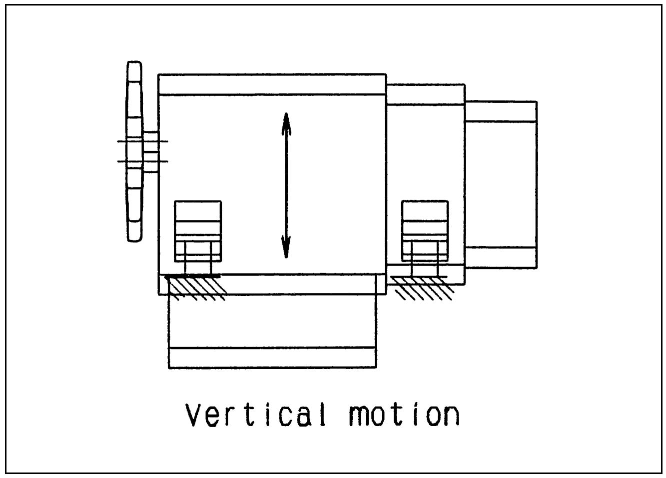


Fig. 11-7 Vibration characteristics of 3 cylinder engine

(2) Four-cylinder engine's vibration characteristics

Engine's motion	Vertical
Rotational degree	2nd order
Remarks	Caused by reciprocating secondary inertial force. Aggravated with increasing rpm.
Engine's motion	Rolling
Rotational degree	2nd order
Remarks	Caused by torque variations.



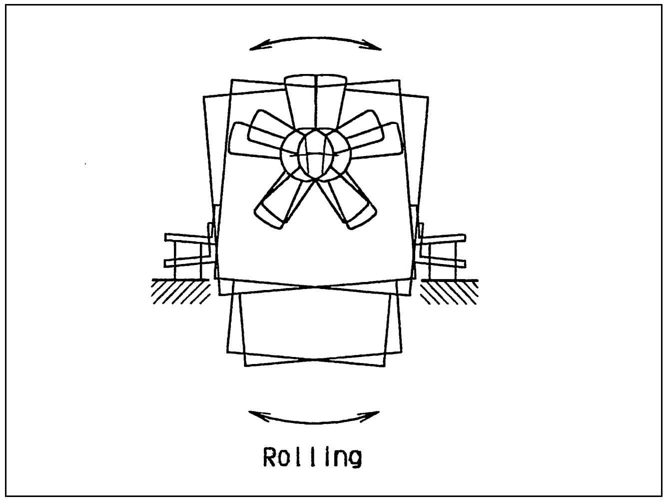


Fig. 11-8 Vibration characteristics of 4 cylinder engine

A particular type of vibration to be noted is the one that occurs near the resonance point at low engine rpm. The natural frequency of a rubber engine moment is somewhere between 5 and 25 Hz. At too low an idling engine rpm, for example, the rolling vibration of an idling engine may be (amplified) by resonance.
It is therefore important to make sure that the vibromotive force of an engine idling at low speed does not resonate.

[DECIDING THE ENGINE MOUNT SPECIFICATIONS]

Fig. 11-9 shows the procedural flow of determining the engine mount specifications.
First of all, measure an engine's and attachments physical properties.

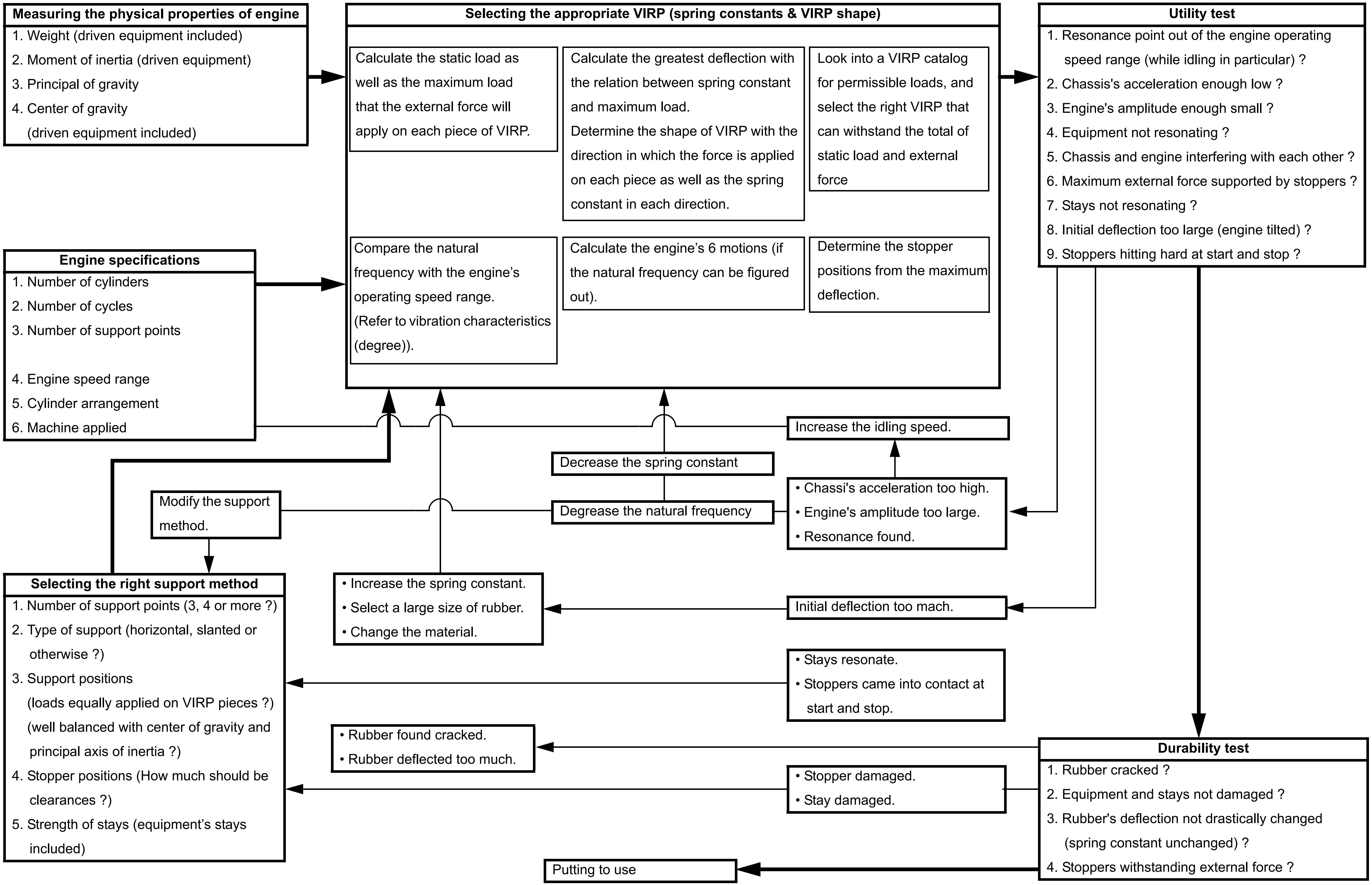


Fig. 11-9 Deciding the engine mount specifications

Considering the engine mounting position and space and other factors, determine the number of support points, support positions, and support method. Then with the engine's physical properties, support method and specifications in mind, select the right type of VIRP.
At this stage, mount the engine on the machine with the VIRP and carry out the utility test and durability test.
Make sure, there is no problem and introduce this type of VIRP.
The next page chapters cover engine support methods, selection of VIRP, possible problems and other related matters.

[VIBRATION INSULATING RUBBER PRODUCTS (VIRP)]

(1) Selecting VIRP

Please consult KUBOTA Engineering or VIRP manufacturer for proper selection of VIRP.

(2) VIRP characteristics

VIRP have the following main features.

- Damping force available
- Spring constants presettable in three axes
- VIRP shaped in a relatively flexible way

For use of VIRP, the following points must be kept in mind.

- Creep phenomenon
- Temperature characteristic
- Oil resitance

1) Creep phenomenon

Since the VIRP has been applied, it gradually suffers from permanent deformation.
Initial deflection comes after the first 2 weeks, and slight, gradual deformation continues thereafter.
This problem must be considered in advance.

2) Temperature characteristics

The VIRP is greatly affected by temperature fluctuations. The higher the temperature, the smaller the spring constant, and vice versa.
The temperature characteristics depend on the types of rubber, but their spring constants suddenly get higher. This means that temperature changes must be understood well. It is also important to adjust test-run temperatures to the practical application.

3) Oil resistance

Some VIRP materials are not resistant to oil and grease. Pick up the appropriate VIRP material that sufficiently withstands oil and grease for engine-supporting applications.

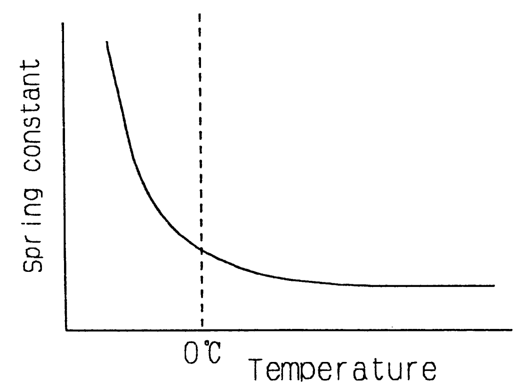


Fig. 11-9 VIRP spring constants versus temperatures

[SUPPORTING PROCEDURE]

(1) Suporting points

In most cases, engines are supported at 3 or 4 points. Whether in a 3-point or 4-point support design, all the VIRP points must be arranged to be equally loaded. If any of the VIRP pieces is under unequally heavy load, not just its durability is affected, but also unusual vibrations may occur. The load upon each of the VIRP pieces is determined by its center of gravity and supporting position. If the support positions cannot be changed and the load cannot be equally distributed, preferably modify the spring constant of each VIRP piece and allow the same level of deflection to all the pieces.

This helps keep the engine at a level.

1) Three-point support positions

A typical 3-point support is shown in Fig. 11-10.
In this design, both sides of the crankcase toward the fan as well as the bottom of the flywheel housing are supported.

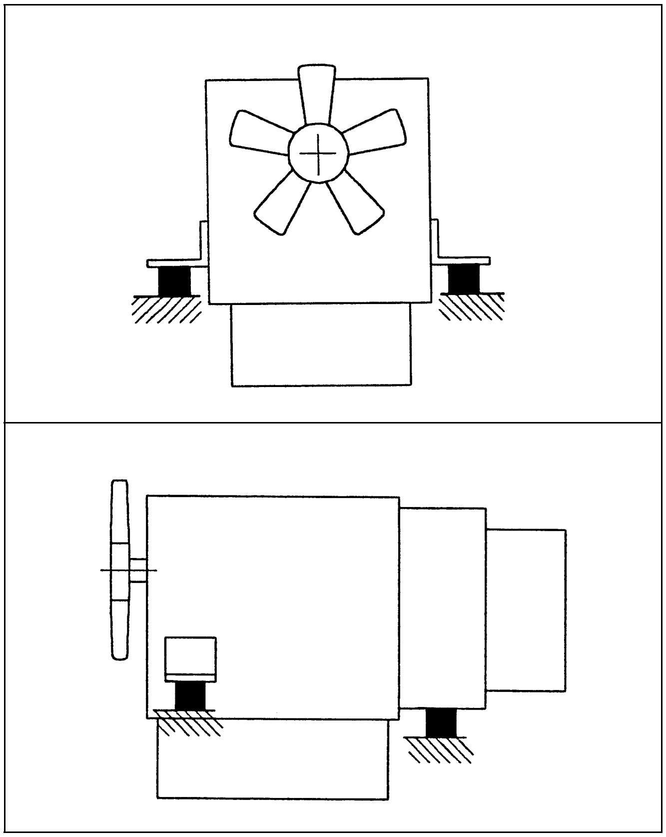


Fig. 11-10 Typical 3-point support arrangement

2) Four-point support positions

A typical 4-point support is shown in Fig. 11-11 and Fig. 11-12.
In this design, both sides of the crankcase toward the fan as well as both sides of the flywheel housing are supported.

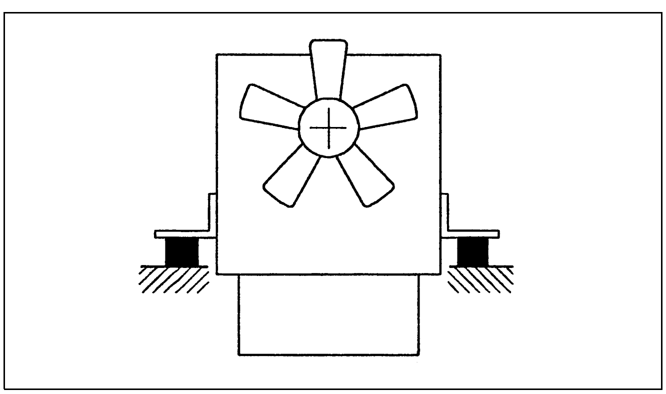


Fig. 11-11 Typical 4-point support arrangement

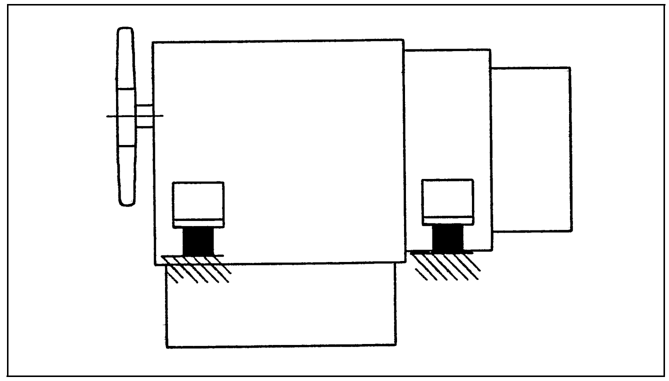


Fig. 11-12 Typical 4-point support arrangement

(2) Support stay configurations

Most general-purpose engines are supported at 4 points. There are two common ways to support them : horizontal stays and slanted stays.

1) Horizontal stays

The horizontal stays are shown in Fig. 11-13.
This is the simplest method in a compact way.
To keep the natural frequency low in this arrangement, have the stays as close to the center of gravity of the engine as possible. Because the vibrations occur vertically or horizontally depending on the support positions, it is equally important to find the best support positions.

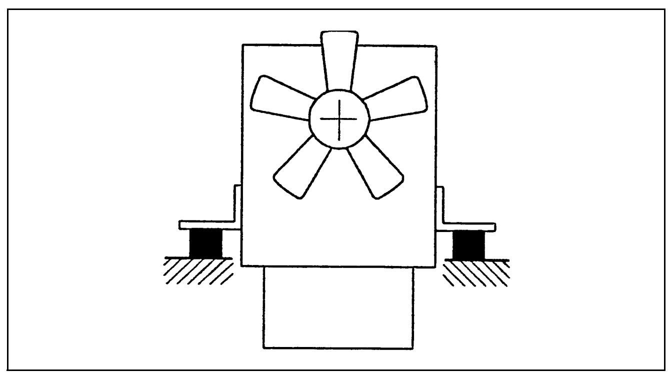


Fig. 11-13 Horizontal stays

2) Slanted (angled) stays

The slanted stays are shown in Fig. 11-14. This method is commonly used when the rolling vibration's natural frequency needs to be lower. Such natural frequency is kept smaller by aligning the shearing direction (softest portion) of VIRP with the rolling direction. The tilt angle θ is determined by the following factors among others.

- Principal axis of inertia
- Direction of external force
- Durability of VIRP

The above factors are discussed one by one next.

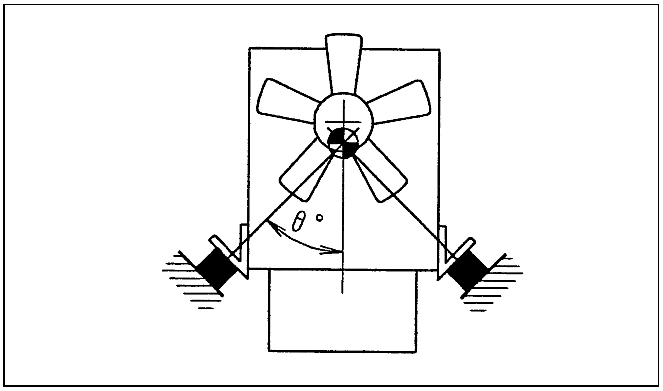


Fig. 11-14 Slanted stays (A)

a) Principal axis of inertia

With the support positions fixed, the natural frequency can be lowered by setting the tilt angle θ along the principal axis of inertia (see Fig. 11-15). Tilt angles of 30∼60° are commonly adopted.

b) Direction of external force

The slanted support system is weak against the vertical external force coming from the chassis.

The tilt angle therefore must be determined by the type of machine. If the vertical external force is applied, narrow the tilt angle θ or raise the spring constant. It should also be noted that the slanted support has a smaller spring constant in the rolling direction and that the vibrations become noticeable at start and stop of the engine.

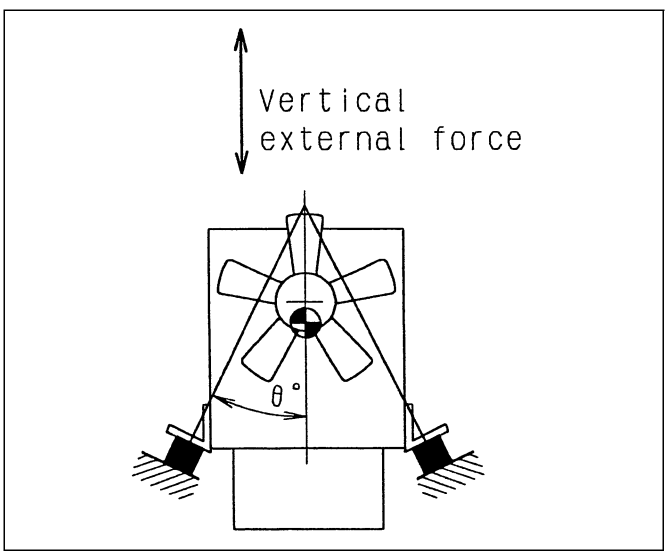


Fig. 11-15 Slanted stays (B)

c) Durability of VIRP

The slanted stays support the engine in the shearing direction, in which the VIRP is most affected, and help reduce the natural frequency.

An extreme tilt angle of θ = 90° must be avoided.

The permissible load of VIRP is generally small in the shearing direction, which may affect its durability. The tilt angle θ must therefore be determined to keep the shearing load low.

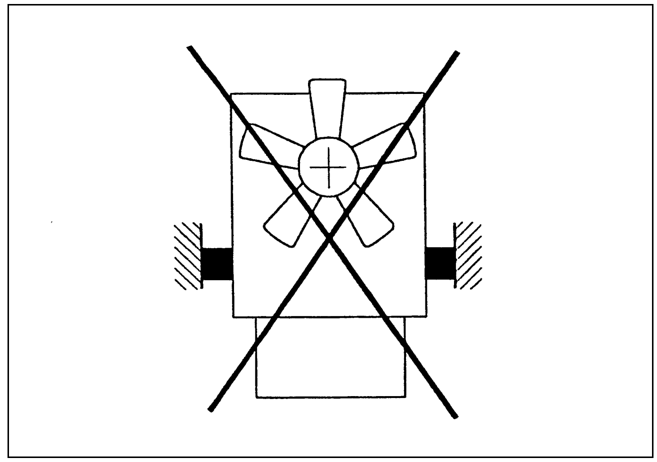


Fig. 11-16 Tilt angle θ =90°

3) Support stays

The support stays should be designed with a sufficient strength margin. The support stays must also be free from resonance with the engine's vibrations because the stays themselves have their own natural frequency.

The thickness of the stays vary from machine to machine. To cope with a great external force as construction machinery, the stays must be designed to be stiff. It is a advisable to have the stays relatively short and place them near the engine.

[ATTACHING EQUIPMENT ON THE ENGINE]

Generally speaking, it is better to place a silencer, air cleaner and other equipment separate from the engine. In many cases, stays for air cleaner, silencer, fuel filter and others are affected much by vibrations, and such equipment is set up easy to resonate. Resonance may damage the equipment and their stays much earlier than expected.

Preferably place those equipment on the chassis and connect them with the engine using flexible pipes or the like. When placed directly on the engine, proper measures must be taken against vibrations. And carry out a durability test with the equipment on the engine to make sure there is no problem. It is important to check related water, fuel and other pipes that are vulnerable to vibrations.

[INSTALLING DRIVEN EQUIPMENT]

Suppose that a hydraulic pump, for example, is to be connected overhanging on the flywheel side of the engine. In this layout, keep in mind the pump's weight and length.
Too heavy a pump changes the center of gravity of the engine mount too much, which gets the flywheel side VIRP overloaded. Also when an external force is transmitted, the engine may move unusually. Too long a pump, increases the amplitude of the pump's end vibration. With this in mind, it is advisable to employ a pump as short as possible.
If a driven unit is too big, preferably adopt a 4-point support method : 2 points for the engine and 2 points for the driven unit. If a driven unit is not just big but also heavy, a 5- or 6-point support way could be better : 4 points for the engine and 1 or 2 points for the driven unit.
Fig. 11-17 shows a typical side-by-side layout of an engine and a driven unit. As shown here, place the VIRP under the entire system including the engine.

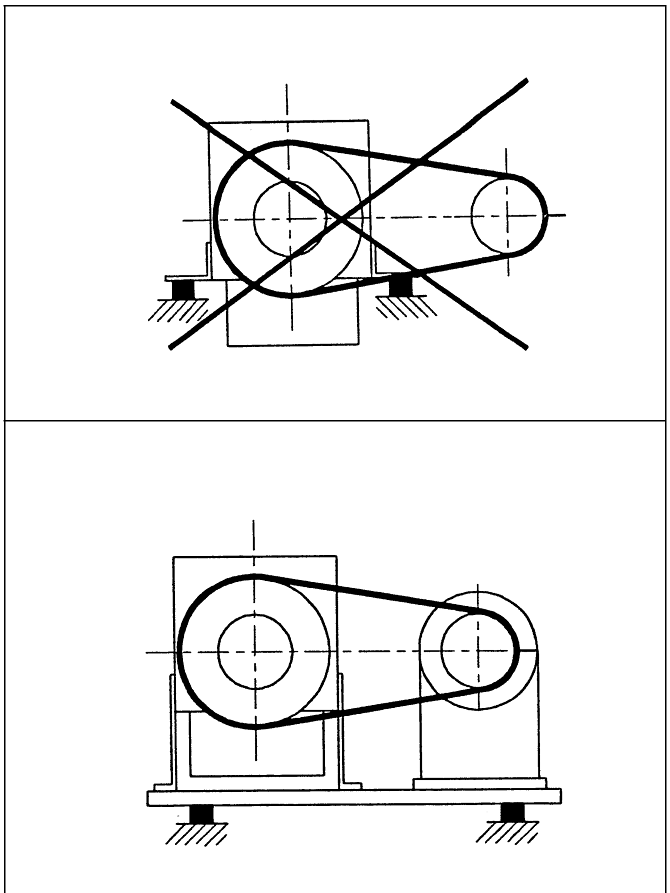


Fig. 11-17 Engine mount in side-by-side setup

[NATURAL FREQUENCY VERSUS RESONANCE]

When an engine is mounted, there surely is a natural frequency. The natural frequency depends on the following factors :
Weght, moment of inertia, center of gravity, support positions, spring constant of VIRP, and principal axis inertia.
In using rubber for the engine mount, the natural frequency must be strictly considered. If the engine runs around the natural-frequency rpm, resonance occurs and the vibromotive force gets amplified up to several times. This may damage the equipment, stays or VIRP pieces, or invite an innterference with the chassis.
The natural frequency can be calculated. In a practical test, however, run the engine in its entire speed range and find an rpm at which the vibration reachs a peak (resonance point) : the natural frequency stands at this rpm. If the natural frequency is within the engine's operating speed range, it is necessary to keep the natural frequency below the operating speed range or the lowest operating speed above the natural frequency.
The following measures could be taken in order to reduce the natural frequency.

- Lowering the spring constant of VIRP
- Increasing the moment of inertia (for rotary motion)
- Decreasing the distance from the center of gravity to the support positions (for translational motion)
- Increasing the weight (for translational motion)
- Reducing the number of supporting points (VIRP pieces)

The above ways help reduce the natural frequency and keep the resonance point away from the engine's operating speed range. But the entire amplitude and acceleration may remain the same.
When the spring constant of VIRP is made smaller, for example, the natural frequency becomes lower too. The smaller the spring constant, however, the less the VIRP can with stand the vibromotive force.
This means that the VIRP may be affected much more by the same level of vibromotive force.
The durability is also degraded accordingly.
The same is true with a smaller number of VIRP pieces.
Just lowering the natural frequency is not sufficient.

Other points that would be adversely affected must be kept. In mind, too.
The engine mount may also resonate by an external force. This is called engine shake.
If the resonance point lies at low frequencies of 5~20 Hz, the external force from the chassis gets the engine resonating. In such case, VIRP with great damping force must be used.

[PRECAUTIONS IN SWITCHING TO DIFFERENT-TYPE ENGINE]

Suppose the VIRP is used for an engine of different type from the previous one.
It is essential to consider a quite different design of engine mount.
This is because a different-type engine requires a different set of VIRP factors. Here are the points to remember in selecting the appropriate VIRP.

- Physical properties of the engine (weight, moment of inertia, center of gravity, etc.)
- Specifications of the engine (number of cylinders, speed range, etc.)
- Supporting method of the engine (support positions, number of supporting points, etc.)

According to these data, the following factors will be different, also, causing a different mode of vibration.

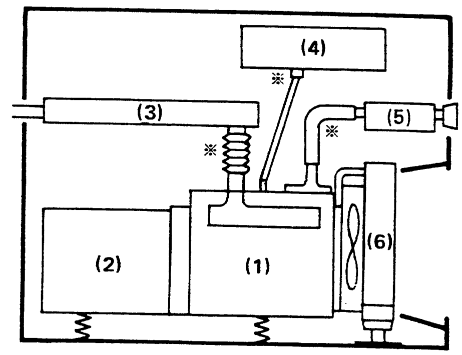
- Natural frequency
- Vibration characteristics of the engine

Take an example of an engine that has nearly the same specifications, except the weight, as those of the previously mounted engine.
The smaller the weight, the greater the natural frequency. This causes the resonance-point rpm to go higher and adversely affects the vibration in the low rpm range. There may be cases in which the engine mount must be redesigned or the idling speed must be changed.
Now we have another example of an engine.
The engine is almost identical in physical properties, supporting positions and piston displacement, but has three cylinders instead of four.
In this case, the vibration characteristics will be different.
With the same engine mount design, the three-cylinder engine produces generally proper vibration characteristics in the low speed range. On a four-cylinder engine, the idling vibration happens at the 2nd order engine vibration ; on a three-cylinder engine, it occurs at the one-and-a half order. Let's say, a four cylinder engine resonates at 600 min^{-1} (rpm).
Resonance occurs at 800 min^{-1} (rpm) on a three-cylinder engine. In such cases too, the engine mount must be redesigned or the idling speed must be changed.

In orther words, even through the chassis remains the same and the engine is almost identical to the previous one, the engine mount design may have to be redesigned in order to keep the vibrations low.

[PRECAUTIONS IN PIPING WHEN USE RUBBER MOUNT]

If engine and related equipment are supported on different frames, flexible piping must be used.



(1) Engine	(3) Muffler	(5) Air cleaner
(2) Generator	(4) Tank	(6) Radiator

Fig. 11-18 Example

3. POWER TRANSMISSION DEVICE

[FLEXIBLE COUPLING]

Torsional vibration and impact of the drive shaft can be absorbed by a flexible coupling which prevents them from being transmitted to the driven shaft. Installation of such a coupling between the engine and driven shaft is limited by available space. A flexible coupling also prevents torsional vibrations and impacts generated at driven shaft from being transmitted to the engine. There are many types available, such as rubber types, resin types, chain types, tire types and fluid types.
Select according to specific load and use condition.

[POWER CUTOFF DEVICE (Clutches / Disconnects)]

Power cutoff devices (clutches) allow engines to be warmed-up at no load. It is a general practice to install clutches on such as products vehicles, tractors, pump sets ; etc. which can encounter sudden loads.
The following kinds of clutches are available.

Mechanical type	Dry type	● Engagement ● Friction plate loaded type (spring) ··· ∗1 ● Centrifugal clutch
	Wet type	● Friction plate loaded type (spring) ··· ∗2
Electric type		● Electromagnetic clutch ··· ∗3

Note 1 :
The spring loaded type clutches (∗1, 2) are always "IN" and a clutch pedal or lever is used to cut off power against spring force. For this reason, thrust force is applied to the crankshaft and care must be given to prevent use at a load exceeding the allowable limit.

Note 2 :
The electromagnetic clutch (∗3), must be grounded to prevent an electric current from flowing to the crankshaft. Otherwise, bearing metals will be electrically corroded, resulting in possible bearing and crankshaft failure.
Detailed consultations should be held with the engine maker to determine the most appropriate clutch for a particular engine and purpose.

[TORSIONAL VIBRATION]

When an output shaft is directly connected to the crankshaft, it is necessary to examine stresses caused by torsional vibration of the shaft system depending on rigidity and inertia force of connecting shaft system. When connecting the engine directly to generator, compressor, pump, air blower, etc., contact KUBOTA.

4. SPEED CHANGE DEVICES

The following kinds of speed change devices are available.

1) Mechanical type : Gear speed change devices
2) Fluid type : Torque converter
3) Fluid type : Hydrostatic transmission (HST)

Efficiency is a common factor of an engine regarding load characteristics against engine characteristics and adaptability to using conditions and its frequency.
Fluid types allow stepless variation of torque and speed.
Efficiency is lower than a mechanical type and varies greatly depending on speed range, so that matching should be done carefully.
Fluid types also require special maintenance since oil is used as the transmission a medium.
Various factors, including oil temperature, heat dispersion, rising of starting temperature limit due to resistance increase at cold starting must be considered, along with oil viscosity for use in cold weather.
Oil viscosity, and increased viscosities due to low ambients are important considerations.

5. OPERATING MECHANISM

If an engine is covered ; starting, speed changing, and stopping must be controlled remotely via a mechanical (rod or wire) or an electrical system.
In this case, consider clearances of link mechanism, wear and aging factors carefully. Improper installation will adversely affect engine performance.
Provide special attention to frequency of use and force applied to levers.

6. OTHER PRECAUTIONS

1) When both the engine and transmission machine are directly connected and fixed, rigidity and strength of the mounting base must be considered carefully.
   i.e. Material, plate thickness, flatness, roughness, etc.
2) Engine mounting stands and fixing bolts must have sufficient rigidity and strength.