POWER TOOL DESIGN FOR GOOD ERGONOMICS

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To design a powertool for good ergonomics can be described as the challenge to find the best compromise between a number of contradictory requirements. The different ergonomic factors need to be compared to each other and the development should be focused on the most important criteria. With the aid of an ergonomic evaluation method it is possible to do that.
In this presentation focus is given to design principals for one of the several important factors for good ergonomics, vibrations.
Vibration can often be kept low when you know the vibration sources and make the design taking all vibration sources into account. Some examples of vibration controlled tools will be explained showing how different methods need to be used to control vibration in different too types.
In this paper several examples are given to show the thoughts behind the vibration control of modern industrial power tools

Hand-Arm vibration, Tool design

1 Introduction

Work with hand-held power tools can be found in most industries all over the world. In all cases this type of work exposes the operators to different kind of loads. It can be things like gripping-forces, feed-forces, exposure to vibration and noise, holding hot or cold surfaces and the exposure to dust. Designing a power tool with good ergonomics is a matter of finding the best compromise. As a simple example, increasing the mass is not acceptable because it will increase the forces needed to handle the tool. At the same time increased mass will in most cases reduce the vibrations.
Many tool manufacturers have worked hard over the years trying to find technical solutions to control vibrations in hand-held power tools without negative effects on the efficiency of the tools or on the other ergonomic parameters.

2 Forces acting on the tool cause vibration

Tools for industrial use must be of very robust design to withstand the very hard use they can be exposed to. Industrial tools are therefore normally designed with the main parts made of metal. From a vibration point of view this means that most tools can be regarded as rigid bodies, especially because the dominating frequency normally is equal to the rotational frequency of the tool spindle or the blow frequency for a percussive tool. This is frequencies that are with few exceptions below 200 Hz.
Handles however can not always be regarded as rigidly connected to the tool. There are several examples of weak suspensions designed to reduce vibration transmitted to the hands of the operator. There are also examples of designs where the handles just

happened to be non-rigidly connected and in some cases just happened to be in resonance within the frequency region of interest.

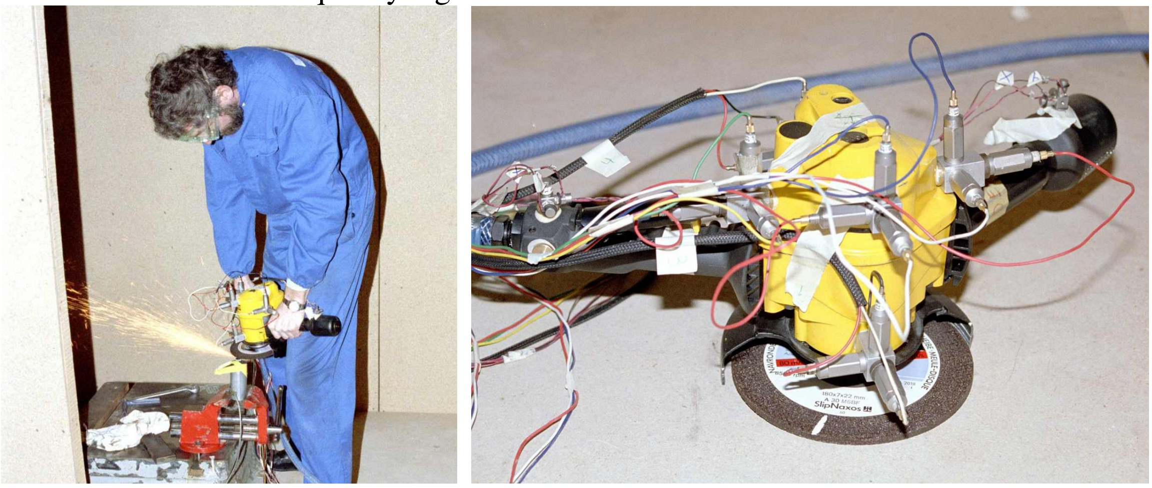

Fig 1 Example of a grinder being investigated with running mode analysis to find parts that are not rigidly connected to the tool housing.

Oscillating forces act on this body and the result is vibration. The oscillating forces are either independent of the work process or process dependent forces.
The forces independent of the work process originate from e.g. the unbalance of internal parts in rotating machines or the unbalance of inserted tools. The forces necessary to accelerate the piston in a percussive tool are also examples of this type of forces.
Process dependent forces are e.g. generated when a grinding wheel is in contact with the workpiece or when the shock-wave, in a chisel on a percussive tool, is reflected back into the tool from the workpiece. The contact force between the bolt and the socket, when an impact wrench is tightening a bolt, is another example of a process dependent force.

3 Design principals

In all cases forces are the source of vibration. This leads to the three basic principles to control vibration:

- **Control the magnitude of the vibrating forces**. Examples are the balancing unit on a grinder or the differential piston in a chipping hammer.
- **Make the tool less sensitive to the vibrating forces**. Examples can be when the mass of the guard on a grinder is rigidly connected to the tool to increase the inertia of the tool.
- **Isolate the vibrations in the tool from the grip surfaces.** Examples are vibration-dampening handles on grinders or pavement breakers and the air-spring behind the blow-mechanism in a riveting hammer or the mass spring system in a chipping hammer.

3.1 Control the magnitude of the vibrating forces

Forces can be reduced in many different ways. For rotating machinery the balance of the rotating parts is essential. The inserted tools that will be mounted on the tool often give a major contribution to the unbalance of the rotating parts. This is a problem because the tool manufacturer has no control over the inserted tools. The only thing that

can be done is to design flanges and guides for the inserted tools to fine tolerances as close as possible to the tolerance interval for the inserted tool.
For percussive tools the reaction force counteracting the force that accelerates the piston is often a major contribution to the vibrating forces. In some designs it is possible to have the reaction forces to act on the workpice instead of the tool body.
Limiting the power of the tool will in most cases also reduce vibration but that is not a possible route because lower power leads to increased usage-time to get the job done and that would negatively affect the daily exposure.

3.2 Make the tool less sensitive to the vibrating forces

A tool will be less sensitive to oscillating forces when mass and or inertia is increased. To increase mass can be questioned from an ergonomic perspective. In some cases when a small increase in mass give a big increase in inertia it might still be a good solution. The tool can be regarded as a stiff body suspended in weak springs. Therefore it will move around its centre of rotation. The perpendicular distance between the forces acting and the centre of rotation will determine how the pattern of movement will be. By altering this distance the movement of the tool can be controlled.

3.3 Isolate the vibration in the tool body from the grip surfaces

To isolate the handles from the vibration in the tool body is the most common thing to do. Modern chain saws and breakers are examples where this principal has been successfully applied. The mass spring system must be designed in such a way that the excitation frequency from the vibration in the tool is well above the systems natural frequency. This requires a certain mass in the handles or the spring need to be very soft. A correlated problem is that when mass is moved from the main part of the tool to the handles the main part will become more sensitive to the vibrating forces and the amplitude of vibration in the main body will increase.

4 Examples of design solutions

4.1 Vibration isolated handles.

On grinders you often find vibration isolating support handles. It is important to understand that the way the tool behaves changes completely when an isolated handle is used.

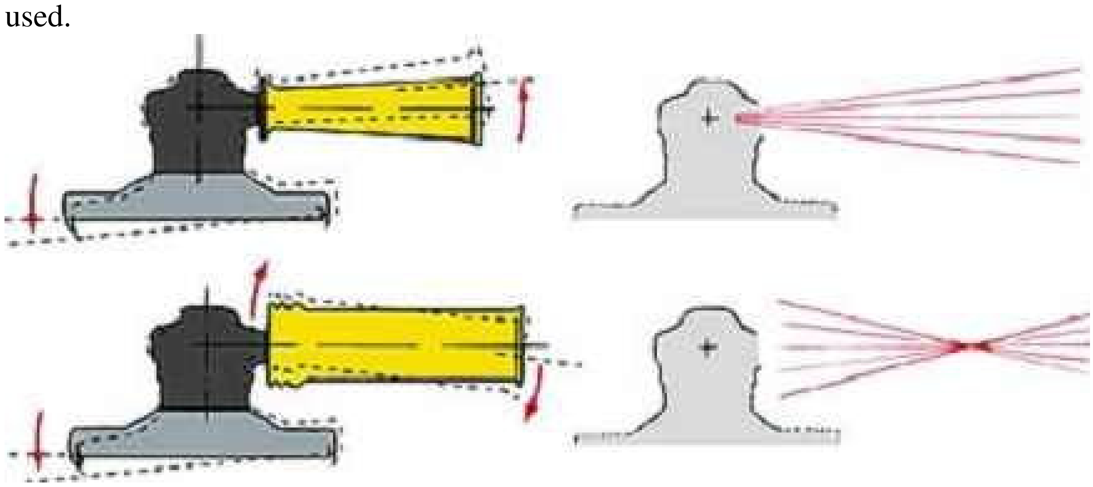

Fig 2 In upper part the rigidly fixed handle move in phase with the tool body. In lower part the non- rigid handle move out of phase with the tool body.

A rigid handle is moving together with the tool. It moves in phase with the tool. The inertia of the handle contributes to minimise the rolling motion around the trigger handle. An isolated handle on the other hand moves out of phase with the tool. The inertia of the handle is no longer connected to the tool and the rolling motion around the trigger handle will increase. The two modes of vibration is shown in fig 2.
As mentioned before an isolated handle works only if the mass spring system consisting of the spring in the handle suspension together with the masses in the tool and in the handle has a resonance frequency well below the rotational frequency of the tool. Often isolated handles are sold with information regarding resonance frequency. Note however that the frequency given is often for the handle itself. When mounted on a tool with limited mass the resonant frequency will increase.

4.2 Vibration isolated chipping hammer

The acceleration of the piston creates internal forces along the main axis of the tool. To isolate the handle from the vibrations created, an isolation with one degree of freedom can be used. A week spring is used between the handle and the percussive mechanism.

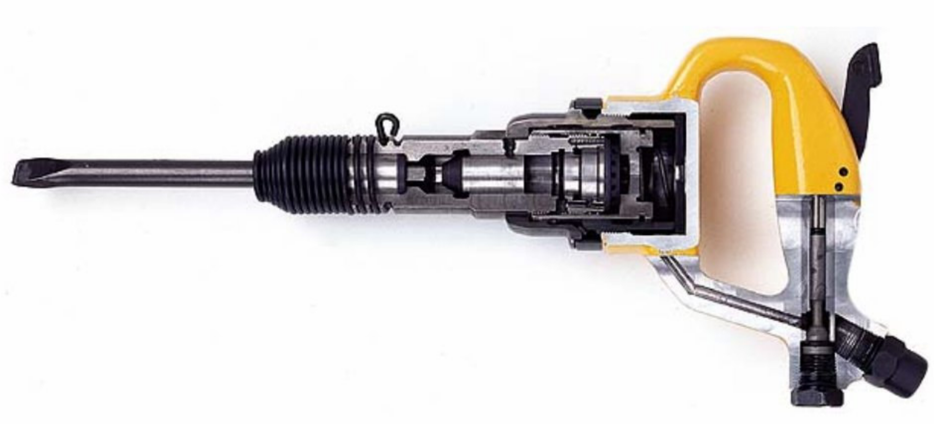

Fig 3 Chipping hammer isolated with a spring between the handle and the percussive mechanism

The drawback with using a linear coil spring as the week element is that it has to be preloaded to be able to transfer the feed force. The result being that the tool needs to be run with feed-forces that allow the spring to act within its active area. Fig 3 shows an example of a chipping hammer with a coil spring.

4.3 Vibration isolated riveting hammer

A riveting hammer must be able to operate within a broad range of feed forces. It is therefore difficult to use a linear coil spring as the active element in a riveting hammer and have good isolation within the whole range of feed forces. In this riveting hammer a volume of air is used as the weak element. The volume can act as a very week spring making the isolation effective. To cope with the wide range of feed forces the air pressure behind the piston is regulated by a servo system. A valve system increases the pressure in the volume when the feed force moves the handle foreword. The flow rate into and out of the volume is limited. The regulation is therefore too slow to react on the forces accelerating the piston but fast enough to adjust to different feed forces. The result is a tool with a suspension that is experienced to be very stiff and at the same time it is actually very week for the vibrating forces giving a high degree of isolation. Fig 4 shows an example of a riveting hammer with an air spring damper system.

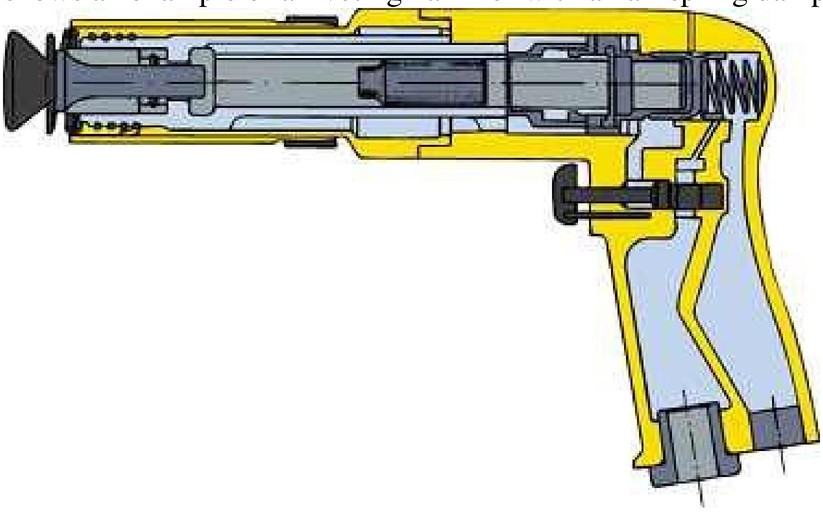

Fig 4 Riveting hammer isolated with an air spring where the air pressure is controlled by a servo piston

4.4 Grinder with low vibrations

In a grinder all three principals for vibration control can be used .On the grinder in this example only two principals are utilised. The result was good enough and the drawbacks with a vibration-isolated handle on a high power grinder were regarded bigger than the advantages. A vibration isolated support handle would reduce the control of the grinder. This tool has an output power of 4.5 kW and the feed forces needed to handle the tool are considerable.

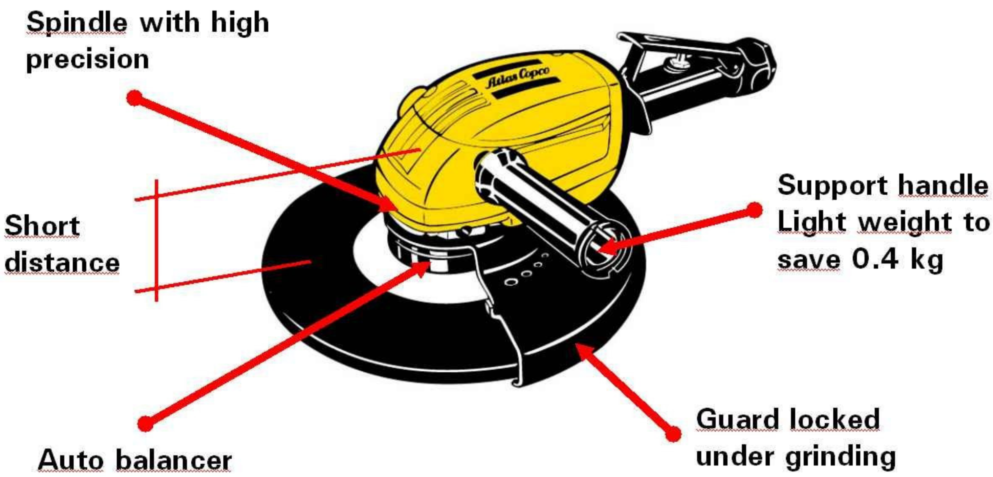

Fig 5 Vibration control of a grinder

The oscillating forces have been reduced by using a spindle design with a very stiff bearing configuration and by designing the flanges to tight tolerances in the upper part of the tolerance span given in the standards for spindles on grinding machines. Also a balancing unit has been used. The balancing unit will bee explained in more detail later in this text.

Make the tool less sensitive to the vibrating forces. It is essential to utilise the mass of the tool to create as much inertia as possible. The guard is often a considerable part of the inertia around the main handle. On many grinders on the market the guard is not rigidly connected to the tool and therefore it is not part of the inertia. On this tool the compressed air is used to rigidly fix the guard to the tool body when the tool is running and at the same time the guard is easily adjustable when the tool is not triggered.

A technical means to automatically reduce the unbalance

The grinder described above has been equipped with a balancing unit to control the unbalance of the wheel. The unit is located on the spindle. It consists of a groove similar to the outer ring of a ball bearing concentric with the spindle. The grove is located inside a sealed unit. In the groove a number of ball-bearing balls are located.

For the normal rotational frequencies the tool suspended by the arm of the operator is a system that is running above its natural frequency. Consequently the spindle will rotate around a centre of rotation and that centre will not be equal to the centre of the spindle.

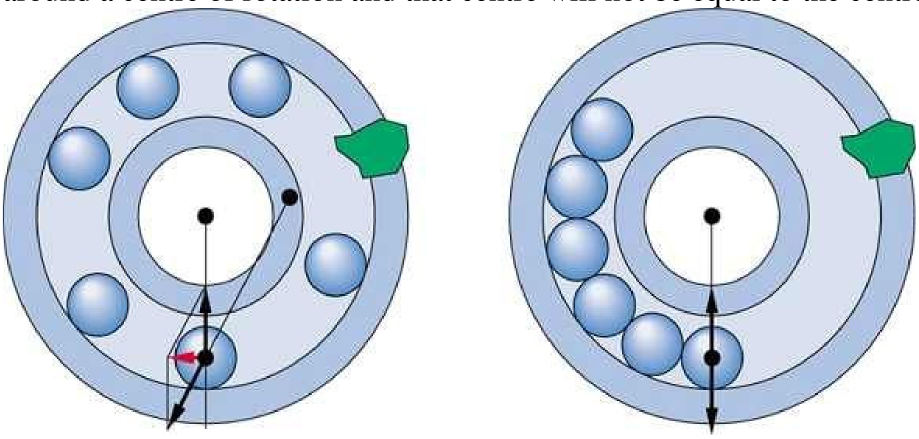

Fig 6 The working principal for an automatic balancing unit

The balls therefore move to positions where they together counterbalance the unbalance of the wheel in only fractions of a second. In fig 6 the forces acting on a ball in a balancing unit are shown.

The vibrations from other sources e.g. from the grinding-wheel bouncing on the surface of the workpiece therefore tend to be more dominating in real grinding. In practice this means that the declared vibration values, according to present standards, from grinders with balancing units tend to be very low. The vibration in a real process is reduced by the balancing unit but not to an extent that corresponds to the often very low declared vibration values.

5. Summary

- An industrial powertool can in most cases be regarded as a still body. The handles are not always part of this still body.
- Forces acting on this stiff body are the source of vibration. The forces are either forces from the process or process independent e.g. unbalances in rotating parts.
- There are three basic principals for vibration control. Control the magnitude of the vibrating forces. Make the tool less sensitive to the forces. Isolate the vibration in the tool body from the grip surfaces.
- All three principals are used in vibration control on power tools either one by one or combined on the same tool.