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VIBRATION FROM HAND-HELD GRINDING MACHINES WITH PARTICULAR REFERENCE TO GRINDING WHEEL UNBALANCE

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INTRODUCTION

This paper discusses the hazard of hand-arm vibration arising from hand-held grinding machines. These are the most widely used portable tools in the United Kingdom which expose people at work to hand-arm vibration. It outlines the factors which play an important role in the vibration generation mechanism and in particular the role played by grinding wheel unbalance and mounting eccentricity.

SOME SOURCES OF VIBRATION

Vibration magnitudes experienced by users of these tools are mainly attributed to:

1. the unbalance within the hand-held grinding machine itself
2. the inherent unbalance in the grinding wheel which depends upon the mounting-shaft eccentricity and its wheel-mass distribution around rotational axis among others. Axial runout in DPC discs may also be important.
3. grinding machine and wheel combination unbalance which in turn, depends upon the method of mounting i.e. wheel mounting eccentricity.
4. grinding machine/wheel interaction with the work-piece which in turn depends upon wheel composition, its dimensions, type, size, peripheral speed etc. and factors such as the work-piece material characteristics, geometrical shape, mounting method mass and metal removing rate etc.
5. the operator's technique.

Recent research including a jointly funded research project sponsored by the European Coal and Steel Community, commissioned by the United Kingdom Health and Safety Executive (HSE) and carried out by British Steel plc [1] has confirmed the work of Eklund [2] and others which concluded that under most normal conditions of use, wheel balance and mounting eccentricity has a major effect on the vibration levels. Therefore grinding wheel specifications need to be developed which, by optimising both mass unbalance and offset, ensuring lower vibration levels for users of these tools at an acceptable production cost.

MEASUREMENT OF VIBRATION

The characteristics of vibration transmitted to the hand from powered tools are often complex. The vibration occurs in three axes and may be different for each hand. The spectra may cover a wide frequency range and the acceleration time histories may in the case of impulsive tools contain very high magnitude shocks.

Vibration exposures are consequently also highly variable with the magnitudes changing from one operation to another and from one operator to another.

Due to the difficulties involved in the measurement of hand-arm vibration, PNEUROP (the European Committee of Manufacturers of Compressors, Vacuum Pumps and Pneumatic Tools), and a working committee appointed in 1974, developed a standardised measurement method and published two reports [3] which deal with measurements on portable grinding machines and chipping machines. The reports are based on Round Robin tests in which six laboratories performed a set standard vibration measurements on four grinding machines. One of the tests was aimed at determining the affect on vibration of fitting a grinding wheel to the machine. When the machines were run at idling speed with different grinding wheels or with the same grinding wheel, which was removed and refitted prior to each test there were significant variations in vibration level due to different wheels of the same category and make and that vibration levels changed each time the same wheel was refitted. The following conclusions were drawn:

1. significant vibration increase when idling with a grinding wheel attached;
2. the dispersion between different wheels is very great;
3. the vibration level changes upon refitting the same wheel. However, success could not be achieved in predicting the vibration level through the change in fitting procedure (e.g. change in tightening torque etc.).

PNEUROP tests showed that after grinding has been carried out for some time, the idling vibration level decreased after grinding for a short time, which suggests that the grinding wheel wears in. Furthermore, the correlation between the level of idling vibration and the level of vibration during work, was found to be weak. The predominant forces often come from unbalance in the grinding tool, and contact forces between the grinding tool and the material. Although the correlation is sometimes weak and the influence of unbalance on the vibration experienced by the operator will vary from situation to situation, it is nevertheless worthwhile (and relatively simple) to improve the quality of grinding wheels and reduce vibration from this source.

Vibration levels invariably increase and unbalance in the tool gets occasionally amplified due to misuse, mishandling of the wheels and lack of or improper maintenance, bent shafts, worn gears and bearings etc. Correct balancing and regular dressing of grinding wheels always reduces the level of vibration. Initial selection of low unbalance wheels goes a long way in achieving this goal.

This research also found that the angle between grinding wheel and work-piece is of particular importance: angles less than 30° can result in uneven wear producing flats on the periphery of wheels causing unbalance, generating higher order harmonics in the vibration spectrum. In the normal use, the dynamic contact forces between the grinding tool and the material are generally of the same order of magnitude as the static feed force exerted on the machine by the operator. If the grinding tool is out of balance, the dynamic contact forces may get greater than the feed force, and in consequence the contact forces momentarily become nil and generates shocks in the system thus creating measurement problems. The PNEUROP work led to the present standard (ISO 8662 Part 4) [4] which is now the accepted test method of vibration measurements on grinding machines.

VIBRATION IN PORTABLE GRINDERS

The purpose of International Standard ISO 8662 is to define test procedures for certain categories of power tool in order to make repeatable vibration measurements. Part 4 of this standard deals with portable grinding machines. The document defines a method of measurement of vibration on a free-running grinding machine fitted with a "dummy" wheel of known unbalance; it is assumed that unbalance in the machine and / or its abrasive wheel is the major source of hand-transmitted vibration and that vibration when free-running is correlated with vibration when grinding. O'Connor [5] explained that this approach was required because a wide range of values were typically found for the unbalance of a batch of new abrasive wheels and these resulted in unacceptably poor replication of results had been achieved in tests when grinding.

The importance of grinding wheel balance has been stressed in the past by several researchers. As already mentioned, the work of PNEUROP resulted in the publication in 1983 [6] of a test procedure for the measurement of grinding machine vibration. This work was reviewed by O'Connor and Frood [7] who stated that the free-running vibration magnitude was a good indicator of grinding wheel unbalance and there is a strong relationship between initial unbalance of the wheel and the vibration produced by it.

They also reported that when grinding, the vibration magnitude in the band of frequencies containing the frequency of rotation of the wheel was highly correlated with the out-of-balance and therefore the measured weighted magnitude was well correlated with the unbalance. (This assumes that the frequency of rotation is dominant in the vibration spectrum after frequency weighting.) Therefore it is necessary to optimise both the mass unbalance and the offset unbalance of grinding wheels, to achieve low vibration levels at an acceptable cost. Eklund et al [2] investigated the influence of the grinding wheel on hand-transmitted vibration and found that the free-running and grinding magnitudes were highly correlated and that the grinding wheel was the principal cause of variability in vibration magnitude.

Clarke and Dalby [8] reported a series of measurements made on a high-cycle straight grinding machine with a 125 mm grinding wheel. They concluded that wheel unbalance (attributed both to wheel mass unbalance and to eccentric mounting on the shaft) was the principal contributor to the vibration levels. They demonstrated that push force was correlated with the metal removal rate; however, no strong relationship was found between the vibration magnitude and either of these two variables. They also found that, under certain conditions of use i.e. the use of powerful electric grinders with high feed forces on high strength materials, vibration magnitudes did not correlate with residual unbalance and spectra revealed high magnitude peaks at multiples of rotational speed. Two of the recommendations made by these authors were that closer tolerances in the size of the mounting holes of abrasive wheels would be required for vibration reduction and ensuring that wheels are correctly fitted to grinder plays a significant part in vibration reduction. In particular fitting wheel flanges the wrong way round can result in a wheel being eccentrically located and hence cause vibration.

With a view to establish the practicability of reducing the exposure of users of the grinding machine by improving the wheel quality, targeted to achieve grinder vibration not exceeding an acceleration level of 2 ms^{-2}, HSE recently commissioned an European Coal & Steel Community sponsored research project. where Clarke et al [9] carried out a series of tests on four types / sizes of grinding wheel each covering a wide range of unbalance, with a view to developing a balance limit specifications for grinding wheels with which its manufacturers could comply at a user acceptable cost. Four wheel sizes that were chosen were 125 mm and 150 mm diameter fitted to straight grinders and 180 mm and 230 mm diameter depressed centre wheel fitted to angle grinding machine. All the grinding machines were of the high frequency type (i.e. powered by 200 Hz or 300 Hz electrical supplies). Three conclusions drawn from the research were:

1. mounting eccentricity was less important than mass unbalance and, generally, the wheel bores were well within the international specifications.
2. in order to ensure that all grinding wheel manufacturers raise their standards of production of grinding wheels, the current FEPA, (the federation of European Producers of Abrasive Products) and ISO standards relating to wheel unbalance and bore size should be revised to reflect the level of specification currently attainable. For all wheel types the clearance between wheel bore and grinder shaft be limited to 0.2 mm which may require the manufacturers to tighten the tolerances. Due to the difficulties of production, to manufacture these wheels at an acceptable user cost, in the case of 180 mm and 230 mm diameter depressed centre grinding wheel a peripheral mass unbalance limit of 4 g be accepted as a short term goal and standards revised as such with a further view to tighten up the lower limits as the manufacturing technology develops.
3. the vibration exhibited by 230 mm diameter depressed centre grinding wheels should be a subject of further research.

SOME TYPICAL GRINDING MACHINE VIBRATION LEVELS

As part of a series of projects for The United Kingdom Health and Safety Executive, to assess the extent of the problem of hand-transmitted vibration levels, Pitts [10] investigated vibration exposure in the Foundry Industry. He reported some typical levels associated with the use of portable grinding machines prevalent in the industry at eight UK foundries. These measurements are based on cast steel components of varying size from small castings, which could easily be held in one hand, to very large castings of 1 to 2 tons. The levels of vibration given below were measured for both hands holding the portable grinding machine.

Table 1.

Tools	component size	ms^{-2})		Vector sum (ms^{-2})	
		Left	Right	Left	Right
Straight grinding machine 230 mm	very large	6.6	8.2	8.6	10.7
Straight grinding machine 150 mm	large medium small	2.2 6.4 1.9	2.1 6.4 2.1	2.9 6.8 2.4	2.8- (20.8)max 6.9 2.7
Straight grinding machine 50 mm	large medium and small	1.8	2.4	2.6	3.3

The above research has shown that apart from other parameters, the grinding wheel unbalance and its mounting eccentricity is a major cause of vibration in hand-held grinders. Therefore it is necessary to develop specifications to optimise both the mass unbalance and the offset unbalance of grinding wheels to achieve low vibration levels at an acceptable product cost. Keeping the above in view, work is underway in Europe, on the revision of the standards dealing with grinding wheel quality. To further the goal, HSE are currently undertaking research, to identify, quantify and rank in order of importance, those characteristics of portable, hand-held grinders which significantly influence the vibration exposure of grinder users with particular emphasis on wheel unbalance, mounting eccentricities, applied feed force and type of power unit etc.

HSE has recently published a book [12] of guidance on Hand-Arm Vibration. Its purpose is to provide guidance for those who have duties under the United Kingdom's Health and Safety at Work etc. Act and other relevant legislation. The book is intended as framework document and source of reference for use by those involved in identifying and controlling Hand-Arm Vibration Syndrome risk.

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3. CONCLUSION

The development of open-loop control strategies for flexible manipulator systems using filtered torque inputs has been presented and verified within a constrained planar single-link flexible manipulator environment. *Open-loop control methods* involve the development of the control input by considering the physical and vibrational properties of the flexible manipulator system. The control input is to minimise the energy input at system resonance modes so that system vibrations are reduced. Band-stop filtered torque input functions has been developed and investigated in an open-loop control configuration. Remarkable improvement in the reduction of system vibrations has been achieved with these control functions as compared to a bang-bang torque input. Band-stop filters can be utilised to reduce spectral energy as selected (dominant) resonance modes of the system. However, if the spectral energy around a large number of resonance modes of the system contribute significantly to system vibrations, it will be more desirable to utilise low-pass filtered command inputs.

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