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Poor Quality Of Product Design As A Cause Of Occupational Health Hazards: A Case Study

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Abstract:Quality of product design, which is expected from manufacturers on world market these days, could be provided exclusively by integral approach to product design. Such approach aims to achievement of optimal design solution of product, which is in line with a number of requirements, conditions and limitations of functionality, technology, market and usage. Only those manufacturers who are able to provide such approach to product design have prospective on market. This paper deals with a case study of neglect of integral approach to product design and its consequencies, in order to spread awareness of necessity of its adoption. Scope of this case study is focused on bridge crane whose working vibrations are meant to be potential cause of occupational desease of spinal column of crane operator.*

Keywords**:** *Quality, product design, occupational health hazards, vibrations, ISO 2631-1*

1. INTRODUCTION

Integral approach to product design aims to achievement of optimal design solution of product, which is in line with a number of requirements, conditions and limitations of functionality, technology, market and usage. Basic properties, which have to be taken into account during product design in order to provide design solution of product which successfully operates and which is adjusted to conditions of manufacturing, selling and usage are shown in Figure 1 /7/.

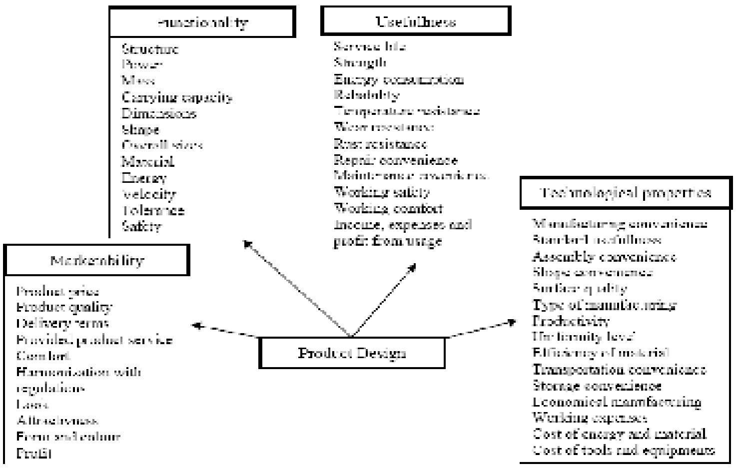

Figure 1.

Therefore, product has to posses a number of properties, which define its functionality, technological properties, marketability and usefulness in order to reach quality of product design acceptable to market. Neglect of integral approach to product design usually leads to design solution of products whose properties do not satisfy requirements of market and consequently such products cause lose of status on market of product manufacturer.

This paper deals with a case study of neglect of integral approach to product design and its consequences, in order to spread awareness of necessity of its adoption. Scope of this case study is focused on bridge crane whose operators reported, during long period of time, problems regarding discomfort caused by severe crane working vibrations and also problems regarding low-back pain.

In additon to body weight load of spinal column is dominatelly influenced by vibrations that are transfered from working machine and act upon whole body of operator. Vibrations have been recognized as a cause of spinal loading at twenties and thirties of last century simultaneosly with widespread of mobile machine. Afterwards many investigations of influence of working vibrations upon occupational deseases have been conducted throughout the world. Conclusion of the investigation conducted by P.Bongers and her co-workers is that working vibrations of bridge crane could be potential cause of low-back pain at crane operators /5,6/. Low-back pain is most frequently caused by degenerative changes of intervertebral disks.

With respect to reported problems of crane opertors and results of investigation conducted by P.Bongers there has been conducted investigation of working vibrations of bridge crane. Obtained experimental results are compared with recommendations proposed by an international standard ISO 2631-1 in order to check if working vibratons of bridge crane could be potential cause of health hazards at crane operators.

2. METHODS

2.1 Experimental research: Object and equipment

Investigation of working vibrations has been conducted on bridge crane shown in Figure 2. Dimensions of cross section of bridge crane girders are also shown in the same figure. Span of bridge crane girders is 30 m and maximal load capacity is 5 t. Long span and elasticity of bridge crane girders cause severe vibrations taking place while crane operates.

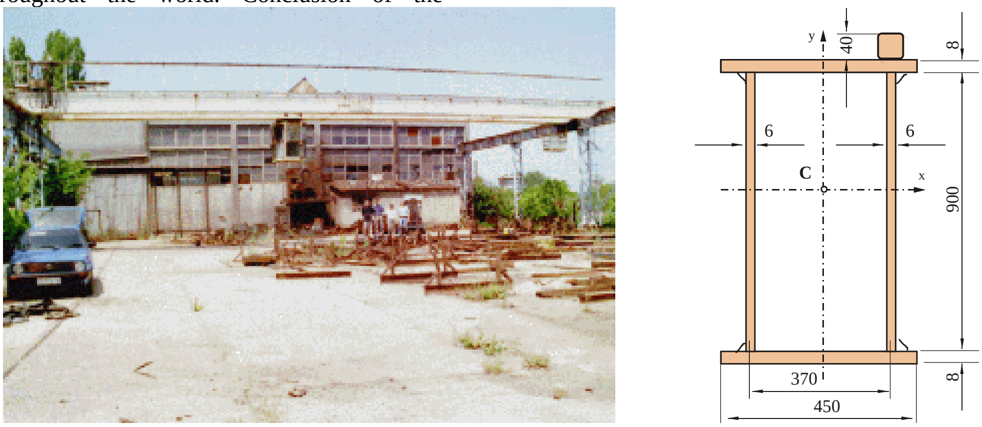

Figure 2.

Experimental equipment for investigation of vibrations, shown in Figure 3, is consisted of: accelerometers HBM B12 of accuracy class 05, amplifier HBM 9012 C i laptop computer with softwer for experimental data processing

Figure 3.

2.2 Experimental research: Results

Acceleration of bridge crane vibrations have been investigated during representative working regimes of bridge crane. During investigation bridge crane has been loaded by load of 4 t that is equal to 80% of maximal load capacity of bridge crane. Accelerometers for investigation of horizontal and vertical vibrations of bridge crane have been fixed to seat of crane operator. Diagrams of acceleration spectra of bridge crane shown in Figure 4 are part of the results of this investigation obtained during the following working regimes: 1-gradual load lifting from ground, 2-gradual load lowering to ground, 3-driving with load and 4-sudden load lowering until its impact to ground /8,9/.

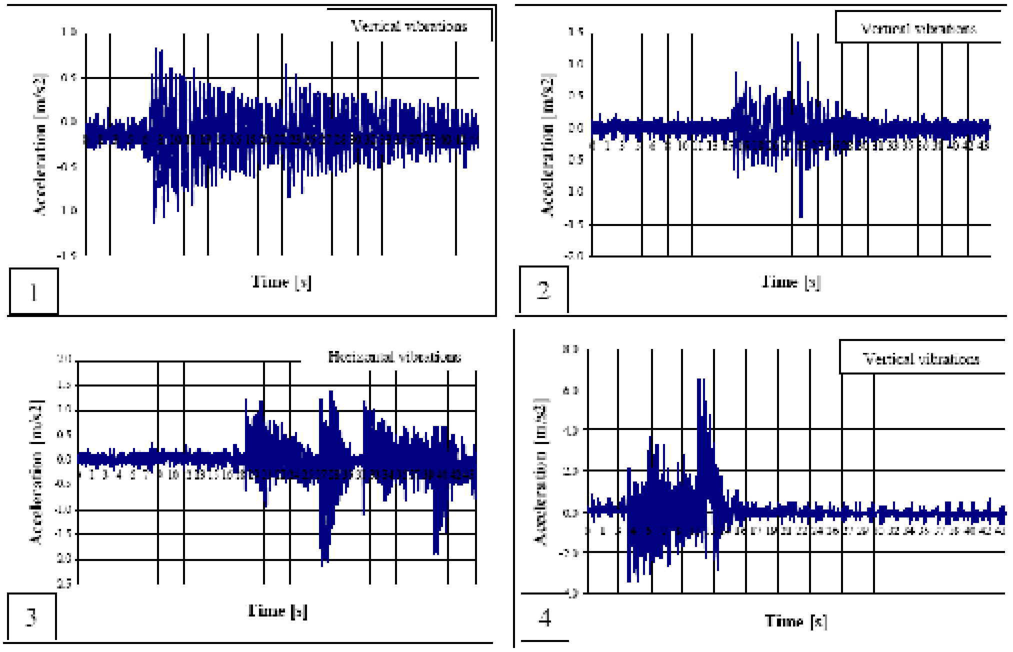

Figure 4.

2.3 Vibration analysis according to standard ISO 2631-1

Every days exposure to influence of whole-body vibrations may cause health problems, it also influences on working activities and comfort. Thereby, influence of whole-body vibrations is object of an international standard ISO 2631-1 /1/. This standard classifies influence of this type of vibrations on health, working activities and comfort. According to ISO 2631-1 third-octave band analysis of acceleration spectra is applied for evaluation of vibration influence on human body. According to third-octave band analysis, frequency range of vibration spectrum, that human body is exposed to, is divided to subranges of width equal to one-third octave with mean frequencies in accordance with standard ISO 266 /2/. For such frequency bands of one-third octave width effective acceleration could be determined by the following equation:

$$a_i = \left[\frac{1}{\tau_i} \cdot \int_0^{\tau_i} a_i^2(t) \cdot dt \right]^{\frac{1}{2}}, \qquad i = \overline{1,n} \quad (1).$$

After determination of effective acceleration of one-third octave frequency bands, crest factor of investigated vibration spectrum could be determined by the following equation:

$$f_c = \frac{a_{max}}{a_{i,max}} \quad (2).$$

In case that crest factor is not greater than 9 evaluation of vibration influence on working comfort of crane operator is based on overall effective acceleration of vibration spectrum according to ISO 2631-1. Overall effective acceleration value of investigated vibration spectrum is determined on basis of effective acceleration of one-third octave frequency bands. Regarding different influence of vibrations within different one-third octave bands on human body, overall effective acceleration is determined by weighting of effective acceleration of one-third octave bands, in a way proposed by ISO 2631-1:

$$a_w = \left[\sum_{i=1}^{n} \left(w_i \cdot a_{w,i} \right)^2 \right]^{\frac{1}{2}} \quad (3).$$

3. RESULTS AND DISCUSSION

Results of third-octave band analysis of bridge crane vibration spectra, for chosen working regimes, according to standard ISO 2631-1 are shown in Figure 5 /9/.

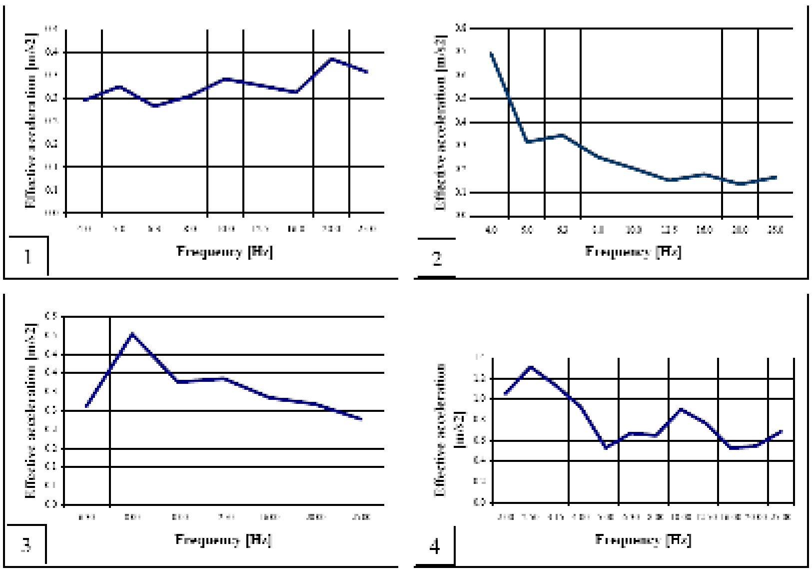

Figure 5.

Crest factor values of chosen working regimes are: f_{c1} =3.32, f_{c2} =7.76, f_{c3}=7.74 and f_{c4} =3.14 /9/. Regarding such crest factor values, that are less than 9, evaluation of influence of vibrations on health and working comfort of crane operator is based on overall effective acceleration of investigated vibration spectra. Values of overall effective acceleration of investigated vibration spectra of chosen working regimes are: a_{w1} =0.72 m/s^2, a_{w2} =0.92 m/s^2, a_{w3} =0.18 m/s^2 and a_{w4} =2.44 m/s^2 /9/.

Lower and upper limits of exposure duration of human body to influence of vibration spectra have been determined for chosen working regimes based on values of overall effective acceleration of vibration spectra. Human body is allowed to be exposed to influnce of vibration spectra exceeding lower limit of exposure duration if certain preventive measures are undertaken in order to decrease effects of vibrations on human body. On the other hand human body is not allowed to be exposed to influnce of vibration spectra exceeding upper limit of exposure duration because of lose of working ability and possible health hazards. Obtained values of lower and upper limits of exposure duration are given in Table 1.

Table 1.

Vibration spectrum	*1*	*2*	*3*	*4*
Time range [h]	*3.5 ¸ 12*	*2 ¸ 6*	*Unlimited exposure*	*0.35 ¸ 0.75*

It has been descriptively evaluated influence of vibration spectra of bridge crane on working comfort of crane operator. Obtained results are given in Table 2.

Table 2.

Vibration spectrum	*1*	*2*	*3*	*4*
Comfort	*Fairly uncomfortable*	*Uncomfortable*	*Not uncomfortable*	*Extremly uncomfortable*

Upper limit of exposure duration of working regime No.4 is only 45 minutes. Such low upper limit of exposure duration indicates possible lose of working ability and health hazards. Conditions of working comfort of majority of chosen working regimes are evaluated as uncomfortable with certain diferences in level of discomfort.

Maximal values of effective acceleration of investigated vibration spectra have been found for working regimes with load lowering to ground: within third-octave band with mean frequency of 4 Hz for working regime No.2 and within third-octave band with mean frequency of 2.5 Hz for working regime No.4. Therefore, the most severe working vibrations of bridge crane are within range of low frequencies, that are equal or slightly deferente from natural frequency of spinal column that is 4 Hz /4/. Such vibrations with high amplitudes and sitting posture of crane operator could cause degenerative changes of spinal column. Low-back pain is characteristic result of those changes. Resultes, obtained during this investigation, point out that vibrations, in certain working regimes of bridge crane, could play important role in raising of low-back pain at crane operators. The following investigations of vibrations of fully loaded bridge crane could additionally clarify influnce of vibrations on spinal column of crane operators in those working regimes that are not recognized by this investigation as a potential health hazard.

4. CONCLUSION

Design solution of bridge crane, that is object of this investigation, is typical case of neglect of integral approach to product design. On one hand, design solution of bridge crane is optimal choice with respect to properties that provide functionality of bridge crane such as: structure, power, mass, dimensions, shape, material etc. On the other hand too elastic bridge crane girders without adequate vibration absorbers cause very severe vibrations which are, according to results of this investigation, cause of inadequate conditions of working comfort and potential cause of occupational health hazards of crane operator. Therefore, design solution of bridge crane is not in accordance with requirements of usefullness such as: working comfort and working safety. Such product is not adequate to requirements of world market and it is result of poor quality of product design caused by neglect of integral approach to its design.

NOMENCLATURE

$a_i(t)$ - acceleration of vibrations within *i*-th one-third octave frequency band
a_i - effective acceleration of *i*-th one-third octave frequency band
a_{max} - maximal instantaneous acceleration peak value of vibrations
$a_{i,max}$ - effective acceleration of one-third octave band containing value of maximal instantaneous acceleration peak
a_w - overall effective acceleration of vibration spectrum
f_c - crest factor
n - number of one-third octave frequency bands
w_i - weight factor of *i*-th one-third octave frequecy band
τ_i - time of duration of vibrations within *i*-th one-third octave frequency band

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