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Tri-axial evaluation of the vibration transmitted to the operators of crawler compact loaders

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ABSTRACT

Vibrations transmitted to the operators of earth moving machines may be severe under certain working and/or operating conditions. This is even worse when crawler machines are considered due to the hard contact between the track belt and the ground which is not dampened in any way by the air present in the tires as it happens in wheeled machines.

This paper reports a study conducted on different machines in their standard configuration under different operating conditions: two fixed travelling velocities (low and high) on two defined surfaces (a path in asphalt and an artificial normalized track), with and without the presence of a ballast in the bucket and with the same operator driving all the machines. The accelerations were measured either on the seat cushion and on the cab floor in order to detect the amount of vibration transmitted between these two points.

The analysis was primarily focused at the assessment of the acceleration values measured on the cab floor to detect whether they are balanced among the different vector components (x, y and z) and whether they show significant differences among the different machines and operating conditions, in terms of surface, velocity and presence of the ballast. Then, a comparison between the acceleration measured on the floor and those measured on the seat was performed in order to evaluate the seat damping characteristics and to detect the amount of vibration that is transmitted to the operator. Finally, the evaluation of the whole body vibration exposure levels was performed to assess the grade of comfort reasonably perceived by the operator.

Relevance to industry - This paper highlights the importance to review the standard configurations currently used on this kind of machines (cab and seat suspensions): they turn out to be absolutely ineffective to assure the operators of safe and comfortable working conditions. Compact loader manufacturers should consider the vibration problem at the machine design stage and choose cab suspension systems and seats able to reduce accelerations along the three different axes. Similarly, seat manufacturers should pay attention in reducing rolling and pitching effects using specific seat suspensions effective also along the horizontal and lateral directions. Unfortunately standards currently in force do not require to control horizontal and lateral vibrations. Consequently, the address of this issue at ISO level in order to update the current legislation could be a strong stimulus for seat and machine manufacturers and a progress towards the operator comfort.

1. Introduction

Crawler off-road machines generate very high vibration levels during operation that may cause detrimental effects on the operator's health, on his job performance and also on several mechanical and electronic components resulting in their possible premature failure. Due to the periodic impact of the driving sprockets on the moving track belts and the related interaction between track belts and ground, these high vibration levels are at low frequency, generally in the range 8 Hz–40 Hz depending on the tooth number of the driving gear and the machine speed.

The vibrations transmitted through the floor and through the seat to the operator's legs and back (whole-body vibrations - WBV), can have very dangerous effects on the operator's health, causing musculoskeletal disorders and postural stresses, as reported in several epidemiological studies on this subject (Bovenzi et al., 2006; Gallais and Griffin, 2006; Kittusamy, 2002; Seidel, 2005). Many other studies can be found in literature reporting also other negative effects such as changes in blood pressure, heart rate, physical symptoms (tiredness, yawning, sleepiness, tired eyes, and absentmindedness), mental symptoms (irritation, loss of patience, distracted attention), and nervous symptoms (headache, backache, dizziness, nausea, and stiff shoulders) (Zimmermann et al.,

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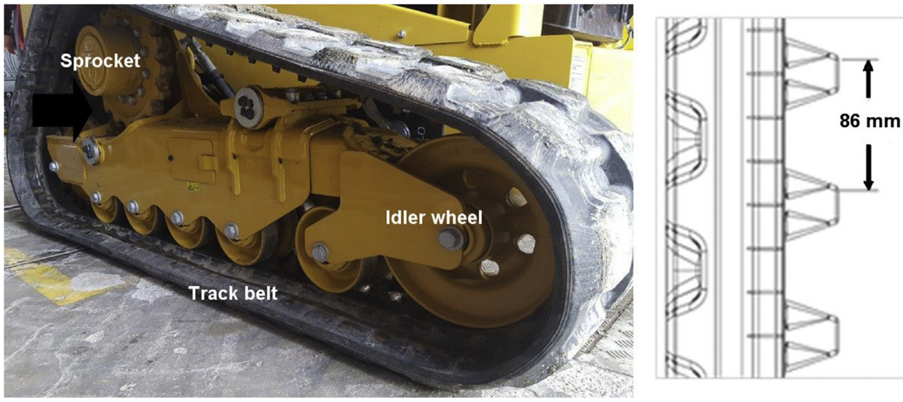

Fig. 1. Running track system.

1997; Kubo et al., 2001; Ljungberg et al., 2004; Ljungberg and Neely, 2007).

Rubber track belts and track belts with rubber-covered iron shoe have become widely used instead of the steel traditional ones on the small-medium size off-road machines as a possible solution to mitigate noise and vibration levels during operation. In addition their use have other advantages: they do not damage the road surfaces and have great operating versatility. On bigger off-road machines, however, their use is very limited as rubber track belts have a reduced tractive force and a lower durability.

Among all types of off-road machines, compact loaders (skid-steer loaders) have become very popular because of their great operating flexibility. They can be equipped with a crawler or a wheeled locomotion system and can be easily fitted with various attachments to perform a variety of tasks in urban areas for residential constructions, in road maintenance works, as well as in the mining and construction industry.

Market research analysts predict that the market of these machines will grow at a compound annual growth rate (CAGR) of more than 7% by 2021 (Technavio, 2017). This increasing population makes the exploration of the factors improving the performances of crawler locomotion systems an important challenge. Some studies can be found showing that the type of rubber, its rigidity, its thickness, the tread pattern are all design features which significantly affect the track performance (tractive force, de-tracking phenomenon) and durability (Bando et al., 1991). Very few data however are available referring to noise and vibration generated by crawler machines and in particular by crawler skid steer loaders during operation. Some studies on wheeled off-road and agricultural machines can be found in bibliography dealing with the consequences of low-frequency vibration on operators, showing that the entity of the risk depends on different variables, such as the terrain type, the travel velocity, the machine working conditions (with material/without any material) as well as the operator driving way (Kumar, 2004; Eger et al., 2011; Loutridis et al., 2011; Costa and Arezes, 2009).

This paper presents the results of a study aimed at collecting and comparing the vibration data relevant to crawler compact loaders. To quantify the level of vibration, field tests were performed on five different configurations of crawler skid steer loaders. To guarantee the comparison among the vibration data from different machines, the variability of the main field parameters was limited and the measurements were performed at two fixed travelling velocities (low and high), on two defined surfaces (a path in asphalt and an artificial normalized track) with the same operator driving all the machines.

The final purpose of this study was not only the characterization of the low-frequency vibration signals transmitted to the whole body by the machine crawler locomotion system but also the evaluation of whether the standard configurations of these different machines, such as the mounted seat type and the layout of the machine controls, can really assure the operators of safe working conditions or rather some design innovations should be introduced.

2. Material and methods

As the target of this investigation was the comparison of the vibration data collected on different machines in different working conditions, the operating conditions were carefully chosen so that they could represent typical working situations for these kinds of machines and, at the same time, they could be as much repeatable as possible. All the vibration measurements were conducted at the CNR-IMAMOTER test facilities.

2.1. Characteristics of the source

The measurements were performed on 3 crawler skid steer loaders from different brands: two of these machines, however, were equipped with two different track belts. Consequently, for the scope of this paper, these machines/track configurations were considered as if they were 5 different machines and were called M1, M2, M3, M4, M5. All these machines were new, had similar mechanical power (45–50 kW, 4 strokes, internal combustion engine) and were tested in their standard configuration, without any optional items.

The main source of vibration in crawler vehicles is the running gear system, which includes track belts, sprockets, idler wheels and support rollers (Fig. 1). In the case of all the tested machines, the undercarriage included a double mesh front idler wheel (17 teeth), a double mesh rear idler wheel (17 teeth) and a 17-tooth driving wheel (sprocket) in which the rubber track belt and teeth engaged with each other - the track belt having a pitch of 86 mm.

Vibrations are generated by the periodic impact of the driving sprocket on the moving track belt when the vehicle is in motion but can also be caused by the interactions between the track belt and other parts: the idler wheels, the support roller as well as the ground.

2.2. Surfaces and machine operating conditions

Vibration measurements were carried out while each machine was travelling on two different surfaces:

- a path in asphalt, 1000 m long, in order to simulate typical working conditions in urban environment;
- an ISO artificial track, 100 m long, in order to simulate extreme working conditions on rocky irregular terrain. The artificial track was prepared according to the provisions of ISO 5008:2002/Cor 1:2005 (ISO, 2005) and consisted of two parallel strips formed of wooden slats 80 mm wide, each slat being separated from the next by a gap of 80 mm. Slats were firmly fixed in a base frame. The movement of a crawler machine on this artificial track causes very