OVERVIEW OF NEW CONCEPTS IMPLEMENTED ON HEAVY MACHINES IN THE RECENT YEARS

Carmen DEBELEAC

Dunărea de Jos University of Galati, Engineering and Agronomy Faculty of Braila, carmendebeleac@ugal.ro.

Abstract: *In the paper, the author addresses a current topic in terms of designing heavy machines so that they have capabilities at the level of performance requirements imposed by manufacturers in the machine construction industry. Thus, the news desideratum, concepts and technologies applied in order to implement them as high-performance functions of construction equipment were reviewed.*

Keywords: *concept, innovation, heavy machines, performance.*

1 Introduction

In this paper, the terms *heavy machines* are referring to the construction machines that are used especially for earthmoving operations (excavators, loaders, compactors, grades, scrapers, dumpers, trucks etc.). These operations mainly are based of four technological tasks: excavating, hauling, spreading, and compacting [Debeleac, 2019]. So, heavy machines are mechanical systems with moving parts, having the role of transforming a certain form of available energy into a form of useful energy, with which one or more working body are operated, depending on the specifics of the machine. The solutions and methods used to set in motion the working parts of a construction machine are diverse, and their operation is currently correlated with ensuring two imperative objectives: maximum productivity and minimum fuel consumption.

Thus, as a natural consequence, equipment manufacturers are forced to find solutions to implement in the form of integrated command and control systems in order to achieve higher and higher performance, thus coming as close as possible to helping beneficiaries to meet their requirements.

In the following will be presented the main modern concepts that underlie the design of construction equipment, exemplifying their applicability through a wide range of technological innovations in the endowment of the most common equipment used on construction sites.

2 Current trends on construction machines industry

Three technical trends shaping the future of heavy machines construction are: advances in autonomous machinery, electro mobility (for zero emission and more efficiency), and telematics (for digitization as goal of Industry 4.0). These complement the already existing requirements regarding [Naskoudakis, 2016]: comfort and safety; productivity, ecology and economy; equipment management monitoring system (with networked control); maintenance and reliability.

Other changes to construction machines encountered by the author are refer to:

- the use on a wider scale of automated commands for unmanned execution tasks (as component phases of the working cycle of the heavy machines). Intelligent machine control is a suite of features that utilizes advanced heavy machine technology in order to increase work productivity (such as dozer, grader, vibratory compactor). The use of semiautonomous or full autonomous heavy equipment on construction sites gives high improvements to job site productivity and increase the site safety;

- smart applications (specifically as tools for Industry 4.0 [Petrov, 2019]) that utilize radio frequency identification (for fault diagnosis/ prognosis [Marindra, 2018], metal structure displacement [Kuhn, 2018], tire pressure sensor, cylinder force sensor etc.) or wireless sensors networks (wireless technologies will grow especially in following areas [Buda, 2010], [Low, 2005], [Paavola, 2010]: event detection, management monitoring, data collection, real-time data acquisition, control etc.);
- object detection technologies (such as pedestrian people [Fremont, 2016], stores material etc.) using GPS, backup cameras, radar, ultrasonic etc.

3 Principles of the innovative concepts applied of heavy machines

3.1 Operator comfort

Operator comfort is becoming increasingly more important in construction machines field, as it supports productivity and worker safety. Thus, designers bring many improvements to operator comfort in terms of the following aspects [Debeleac, 2017]:

a) increasing the interior volume and maximizing the glazed surfaces through an ergonomic design of the interior of the cabins. Due needed to improve comfort can be used some specific methods and one of these represents replacing the conventional method for driving with joystick in place of the handle bar [Chandrakala, 2014] (Fig. 1).

Figure 1. *Examples of joysticks [Cat],[Deere],[Case].*

Placement of joysticks, keyboard, LCD monitors are located in the optimal areas of visibility of the operator for optimal control and maximum efficiency, and the control panels contain audible and optical alarms. The panoramic cab windows give the operator very good visibility of the terrain around the machine and, in particular, of the work equipment (Fig. 2).

Figure 2.*Constructive aspects of the cabines[Komatsu].*

On request, some machines can be equipped with a rear-mounted video camera for better visibility in the work front.

b) cabin air ventilation and heating using air conditioning systems, water heating systems, window defoggers, air filtration and purification systems, air pressurization systems against the ingress of dust particles from the construction site etc.;

c) low noise level in the cab which must meet the regulatory requirements of the European Union (2005/88/EC) indicating the maximum permissible value of the sound power level inside the cab, <108 dB(A).

d) anti-vibration insulation of the operator's seat and the machine cabin. There are advanced soundproofing materials used in the construction of the cabins, significantly reducing vibrations and the acoustic level of noise inside them. In this regard, in order to protect the safety and health of service operators against vibrations and mechanical shocks (conform SR EN ISO 5349-1:2003, SR EN ISO 5349-2:2003/A1:2015) the limit values of their exposure in the cabins of construction machinery or when handling technological equipment that use vibrations in the work process must be observed (vibratory plates and rammers etc.).

In the case of vibratory compactors, they are more recently equipped with integrated systems that ensure the safety of the operating operators. (e.g. for Bomag compactors - *Operator Safety System* [Bomag]). The parameters that directly influence the vibrations transmitted to the hand-arm system or the body are: the acceleration level, the frequency spectrum, the place of contact of the body with the vibration source, the total duration of exposure.

According to standard EN 12096: 1979 the acceleration level for the hand-arm system must be ≤ 2,5 m/s^2 and for the whole body ≤ 0,5 m/s^2. To fulfill these goals, the designers adopt various solutions for vibration isolation of the seat (using mechanical suspensions or active air suspensions) which has perfectly adjustable versions in all directions, but also the cabin of construction equipment (using anti-vibration elements made of rubber, metal springs or combinations between them and silicone oils [Sun, 2014]). Therefore, the support of the chassis on shock-absorbing elements has a great influence on damping of vibrations caused by moving on irregular profile roads of construction sites (Fig. 3).

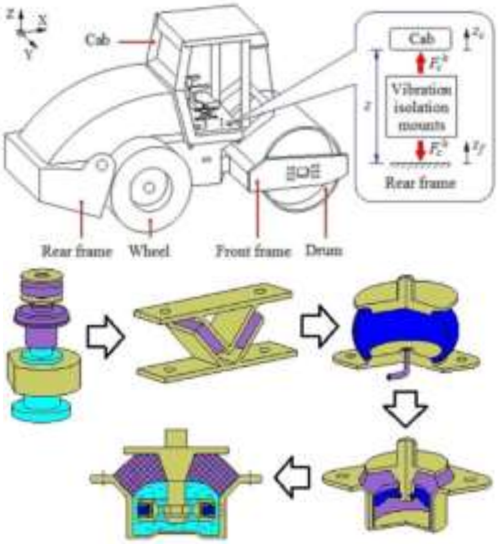

Figure 3. *Cab isolation systems [Nguyen, 2020].*

For operator safety, construction equipment must be equipped with mechanical structures with a protective role, such as FOPS and ROPS structures (Fig. 4) with increased requirements compared to previous models, according to ISO 3449 / SAEJ 231 and ISO 3471 / SAEJ 1040, respectively.

a) *b)*

Figure 4. *Safety systems [Komatsu],[Hitachi]: a) ROPS system; b) FOPS system.*

3.2. Ecology aspects

As a significant pollution and emission sources, heavy machines powered by diesel engines, emit air pollutants such as CO, NOx, HC, PM. Nowadays, the requirement for engines to equip construction machinery must comply with international regulations, ie EU Stage V / US EPA Tier 5, thus complying with the requirements of European standards ISO 8178 on exhaust emissions. Thus, the EU Stage V engines with power output between 19 and 560 kW should not emit more than 0,015 g/kWh of PM and 1x10^{12} particles/kWh of PN. Diesel engines are electronically controlled, with direct injection, turbocharger and high-performance cooling systems. Thus, by using the integral optimization of the combustion process, as well as by using selective catalytic reduction technologies, the equipment manufacturers managed the performance to meet below the maximum limits imposed by the legislation in the field the amount of pollutant emissions (CO, NMHC, NOx , PM) by achieving low fuel consumption even when the machine is running at maximum load [Debeleac, 2013].

Another function with a great impact on reducing fuel consumption is the automatic shutdown of the engine if its operation at idle speed exceeds a certain period of time (for Cat, Komatsu, Hyundai and others construction machines manufacturers).

3.3 Heavy machines drive systems

Regarding the transmission of construction equipment (Fig. 5), it should be emphasized that it is of the Power Shift type (*Full Power Shift Transmission* - for Komatsu machines; *Opti Shift Transmission* - for Volvo machines;

Power Shift Transmission). Recently, Caterpillar manufacturer was implemented the new *Dynamic transmission Output Control* for Cat heavy machines.

a) b) c)

Figure 5. *Transmission types [Volvo], [Cat]: a) I-Shift transmission for Volvo trucks; b) Planetary Powershift Transmission for Cat loaders; c) Dynamic transmission for Cat equipments.*

The steering is operated by by means of hydraulic power servo systems. Most machines have all the driving wheels to develop an increased total traction force so that they can move in the most difficult displacement conditions on construction sites.

Now, the hydraulic drive of construction equipment is based on hydraulic systems with pumps with variable flow rates, with hydraulic power regulators (with proportional flow rates depending on the requirement), *Load Sensing type*, in closed circuits, with load detection.

Load stabilization is another desideratum of heavy machines manufacturers and materializes by controlling the vibrations that occur as a result of equipment maneuvering with maximum load (e.g. the motion of the loader arm / bucket has to be minimized, Fig. 6) or due to shocks at the end of the stroke hydraulic cylinder.

a) b)

Figure 6. *Implementation of Boom Suspension system for reducing the balance of the loaded bucket [Fendt]: a) without system; b) with system.*

3.4. Construction design and versatility

Also, the design of the work equipment is optimized in order to ensure the following performance:

a) achieving imposed kinematic restrictions (eg in the case of loaders it is necessary to keep the parallelism between the bucket and the ground in the lifting phase);

b) development of breaking forces (when tilting the bucket or arm - according to ISO 6015) and lifting with maximum loads;

c) increased resistance to the dynamic stresses to which the metal constructions of the work equipment are subjected.

Currently, there is a wide range of optional equipment for heavy machines in addition to the basic one (eg excavators or loaders are called multifunctional equipments due to the large number of work accessories that are can be mounted instead of the standard one, respectively over 40 work accessories).

The versatility of the machines is expressed by the multiple configurations of the work equipments, by the quick couplings of the work accessories, by the additional functionsperformed by them (Fig. 7).

Figure 7. *Versatility of heavy machines [Hidromek].*

On the other hand, by optimizing the geometry of the coupling system, the lubrication points were reduced, thus minimizing the maintenance costs of the machine.

3.5. Advanced functions

The 3D machine grade control solution (e.g. developed by Leica Geosystems, Inc.) offers în the case of semi-automated excavators functionality, from Liebherr, Case, Doosan, Hitachi, Deere, Kobelco companies, to automatically control boom, bucket, tilt and tilt rotator bucket functions (Fig. 8).

Figure 8. *Application of excavator grade control function [Leica].*

Grading technology with *Assist* function to make excavators, dozers and graders more efficient (to dig faster and more accurate) and reduces the cost of grade checking (to the target design surface as well the cross slope).

The concept of autonomous guidance consists in the control and orientation of 2D (laser) or 3D (eg GPS) of the technological activities performed by the heavy machines. It is noted the use of GPS systems that have an accuracy of 1-3 cm for elevations or systems with robotic total station whose accuracy is 1-5 mm for elevations.

Remote monitoring of equipment (Fig. 9) is a concept already put into practice in order to save time and cost of execution of work performed with them.

Figure 9. *Remote control of the wheel loader [Cat].*

The data about the machines that are equipped with wireless machines tracking systems are transmitted through the web site, which are then processed and provide useful information about the positioning of the machines, but also about their activity through the preparation of daily work reports (Fig. 10).

Thus, can easly identified the major benefits of implementation of theses monitoring systems, such as: machine management, operator management, fleet monitoring, increasing availability of machine in good work condition.

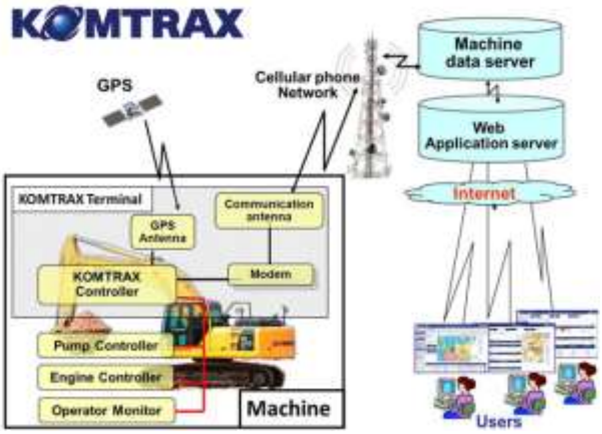

Figure 10. *Wireless machine tracking system - Komtrax [Komatsu].*

4 Conclusions

In this paper, the author aims to outline an overview of the actual requirements with a direct influence on the latest technologies embedded in modern construction of heavy machines in order to have high-performance functional capability on their work front.

As a result of the continuous implementation of new concepts with a direct impact on increasing the level of technological performance, and implicitly, the capacity of construction equipment, the author notes new directions of approach to studies and research in this field and anticipates addressing issues of interest the basis of new concepts and methods of analysis that take into account the fulfillment of the following desideratum:

- align the new technical solutions to be implemented on technological equipment with the requirements and level of demand imposed by specific regulations at European Union level on the following issues of global interest: ensuring operator safety and comfort, limiting the level of environmental pollution in all respects its (acoustics, vibrations, air pollution);
- minimize of fuel consumption;
- increase labor productivity;
- ensure the quality of the executed works;

- need to design versatile equipment to ensure diverse technological functions (to change equipment on the basic machine or to expand work area with them);
- the application of the new intelligent technology (*Smart Technology*) which is also applicable to construction machinery by equipping intelligent command and control systems that replace the commands and decisions of operators regarding the optimal operating regime of the machines throughout the development of phases specific to work cycles, in conditions of maximum performance or, as the case may be, of maximum profitability.

5 References

1. [Debeleac, 2019] Debeleac, C., *Machines and technological equipments for constructions*, Galati University Press, 2019.
2. [Naskoudakis, 2016] Naskoudakis, I., Petroutsatou, K., A thematic review of main researches on construction equipment over the recent years, Procedia Engineering 164, pp. 206 – 213, 2016.
3. [Petrov, 2019] Petrov D., Schmidt M., Hilleringmann U., Hedayat C., Otto T., *RFID Based Sensor Platform for Industry 4.0 Application*, Proc. Smart Systems Integration, 13th International Conference and Exhibition on Integration Issues of Miniaturized Systems, Barcelona, Spain, pp. 1–4, 2019.
4. [Marindra, 2018] Marindra A.M.J., Tian G.Y., *Chipless RFID sensor tag for metal crack detection and characterization*, IEEE Transactions on Microwave Theory and Techniques, vol. 66, pp. 2452–2462, 2018.
5. [Kuhn, 2018] Kuhn M.F., Breier G.P., Clarke T.G.R., *Passive Wireless Sensor for Displacement Monitoring in Metal Structures*, IEEE Latin America Transactions, Vol.16, pp. 1353–1357, 2018.
6. [Buda, 2010] Buda, A., Schuermann, V., Wollert, J.F., *Wireless Technologies in Factory Automation*, IntechOpen Book Series: Factory Automation, Published in March, DOI: 10.5772/9517, 2010.
7. [Low, 2005] Low, K.S., Win, W.N.N., Meng, J.E., *Wireless sensor networks for industrial environments*, Proc. Internat. Conf. on Computational Modelling, Control and Automation, pp. 271-276, Austria, 2005.
8. [Paavola, 2010] Paavola, M. and Leiviska, K., Wireless Sensor Networks in Industrial Automation, Factory Automation, IntechOpen Book Series: Factory Automation, Published in March, DOI: 10.5772/9532, 2010.
9. [Fremont, 2016] Fremont, V., Bui, M.T., Boukerroui, D., Letort, P., *Vision-Based People Detection System for Heavy Machine Applications*, Sensors (Basel), Vol. 16, Issue 1, 128, 2016.
10. [Debeleac, 2017] Debeleac, C., *Innovative concepts implemented in design of construction machines*, Sinteze de Mecanica Teoretica si Aplicata, 8(2), pp. 86-93, 2017.
11. [Chandrakala, 2014] Chandrakala, Md Atiqur Rahman, Ram Krishna, *Design and Development of Special Purpose Joystick*, International Journal of Engineering Research & Technology (IJERT), Vol. 3, Issue 5, 2014.
12. [Sun, 2014] Sun, X., Zhang, J., *Performance of earth-moving machinery cab with hydraulic mounts in low frequency*, Engineering Journal of Vibration and Control, Vol. 20, Issue 5, pp. 724-735, 2014
13. [Nguyen, 2020] Nguyen, V., Vanquynh Le, *Development of cab isolation systems of off-road vibratory rollers: review research*, Mathematical Models in Engineering, Vol. 6, Issue 2, pp. 93-102, 2020.
14. [Debeleac, 2013] Debeleac, C., *About ecological solutions and technologies used on construction site*, Tehnomus XVII, May 17-18, Suceava, pp. 145-148, 2013.
15. [Fendt]https://www.fendt.com/int/tractors/cargo-frontlader-operating-and-ride-comfort
16. [Leica] https://leica-geosystems.com/
17. [Cat] www.cat.com.
18. [Deere] www.deere.com.
19. [Case] www.case.com.
20. [Komatsu] www.komatsu.com.
21. [Hitachi] www.hitachi.com.
22. [Bomag] www.bomag.com.
23. [Volvo] www.volvo.com.
24. [Kidromek] www.kidromek.com.