YIDDISH

Vol 13 Issue 03, Sep 2023
ISSN NO: 0364-4308

Improvement of the Forest Tracked Vehicles' Control byUsing Impulse Control Technology for the Steering Mechanism

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Abstract: To enhance the control of forest tracked vehicles, this research suggests an impulse control technique for the steering system. A "diagonal" steering control scheme and the notion of low-frequency (5–15 Hz) pulse-width modulation of hydraulic pressure are used by the tracked vehicle's steering control system. Various designs for modulators and control systems are shown in the research. We chose the primary settings for the steering control system. The findings informed the development of an experimental control system. With few modifications to the gearbox design, the experimental findings demonstrated that the suggested technique enables the creation of circumstances appropriate for implementing impulse steering technology. In addition, disc slippage might be directly controlled using low-frequency modulation. When developing systems to manage the steering of tracked vehicles, this benefit could be helpful. Creating and evaluating the control system for an updated skidder chassis might be the subject of future research.

Keywords: pulse-width modulation, tracked vehicles, steering mechanisms, closed-loop control systems

INTRODUCTION

Forest management heavily leans on the use of the full tracked chassis machines. In addition to traditional skidders (skidders) and forwarders, typical for the timber industry in Russia, the prospect of introducing small-sized machines hasemerged. The small-sized machines are designed, forexample, to collect non-timber materials, but they are also potentially capable of solving many other problems that are not directly related to logging. Studies of the working tracked skidders show that the machine is in the steer mode for more than 40% of the operating time. Therefore, one of the key problems is to ensure the quality of the tracked vehicle steering control (a smooth change in the turningradius, a one-to-one correspondence of the controlled body position to the radius of the turn. It is desirable to implementthe spot turn operation) (Kováč et al., 2020).

The modern approach to the increase of the tracked vehicle control is based on three modes: the well-proven principle of using hydrostatic transmission as part of a multi-thread steering mechanism, (solutions typical for tanks, for example, for the Abrams, Leopard, Leclerc, Armata and armored personnel carriers "Marder", etc.); the use of the multi-radius steering mechanisms with a large number of fixed radii (for example, a 32-speed transmission described in the work (Claus et al., 2020)); application of electromechanical transmissions (for example, new solutionsproposed in the works (Wu et al., 2019; Gen et al., 2020)).In relation to heavy machines with the on-board gearboxes, an alternative way was proposed - the use of closed (tracking) steering control systems (Yi et al., 2018; Dobretsov et al., 2020).

The use of hydrostatic gears as part of the double-flow transmission allows solution of the problem in complex.However, this type of gear is difficult to manufacture and expensive to purchase. Similar results are achievable in the transmission with the closed steering control system (Yi et al., 2018), in particular, in the double-flow transmission withthe friction controlled steering mechanism (Dobretsov et al., 2020). Prior to the occurrence of technologies creating reliable, compact, and fairly inexpensive high-power electrictraction motors in serial production, the approaches described in the articles (Yi et al., 2018; Dobretsov et al., 2020) were practically unrivaled. Their advancement was restrained mainly by the fact that they were developed for military tracked vehicles.

The emerging trend towards development of tracked vehicles with hybrid power systems allows us to assume thatsimilar technologies can be applied to forest tracked vehiclesserving various purposes. The article (Oh et al., 2017) discusses a new approach to the development of the parallel-type hybrid propulsion system based on the double-flowtransmission. Such approach can both solve the problem of steering control quality and realize the main advantages of the parallel hybrid propulsion system - economy and reliability.

In all cases, we are talking about development of the double-flow transmission with summation of power flows before delivery to the final drive and then to the drive wheel.In all cases, provision for the placement of additional components and assemblies is required. Component density of the transmission layout needs to be also significantlyincreased.

Development of the double-flow transmission, which allows combination of power flows directly on the caterpillar band, is another alternative (Lozin et al., 2019a).

The idea of "diagonal" steering control has been put up for use in large and fast tracked vehicles based on the ideas (Lozin et al., 2019a) (Ni et al., 2019). Modernising the transmissions of skidders and forwarders using these ideas is possible, but, as in earlier instances, it will be too drastic. When developing new machinery, it makes more sense to use such technological solutions. A closed (servo) steering control system based on the concept of impulse control of sliding of the friction unit—which works as a steering mechanism—seems like an acceptable upgrade for the third drawbar category serial chassis when it comes to improving the steering control.

Thus, the research's originality and practical value lie in its adaptation of the impulse control principle of slipping steering discs to a completely new system of "diagonal" steering control, tailored to the traction class machines needed by the wood industry.

A combination of the "diagonal" steering control scheme, servo control principle, and hydraulic pulse-width modulation will lessen the load on the engine and gearbox elements (Gen et al., 2020) and reduce energy consumption when the machine turns, largely as a result of better steering response (Li and Jia, 2017). The driver's weariness will be reduced as a consequence.

Using a digital control system is the next logical step in refining the tried-and-true concepts of brake slip control.

In the future, hyperbolic steering mechanisms based on the friction steering mechanism (Dobretsov et al., 2020) and different hybrid gearbox systems (Zhai et al., 2017) could be used in the steering control systems of tracked vehicles, which is related to the principles of pulse-width modulation pressure.

Under comparable circumstances, friction steering elements find application in gearboxes of both conventional and futuristic unmanned transportation and traction machines (Claus et al., 2020), tracked vehicles' steering gears (Qin et al., 2018; Lozin et al., 2019b), and promising power distribution mechanisms (Zhai et al., 2017; Randive et al., 2019; Dobretsov et al., 2020), among other places.

Therefore, the issue that is typical of transport engineering may be handled using the functioning of a particular brake device as an example, as long as the load balance is distributed appropriately.

Determining the composition of the steering control system, parameters of its elements, and development of its operation algorithms boil down to figuring out the law of pressure change in the hydraulic drive and selecting technology for real-time pressure value monitoring. It has to be a digitally controlled, closed steering control system that can employ CAN interface. If there is a particular brake, the feedback is carried out based on the output speed. The angular velocity of the tracked vehicle's turning rate conducts feedback for the machine motion control system overall, as shown in the example of a caterpillar tractor.

When dealing with comparable control tasks, it is helpful to use amplitude and pulse-width modulation of pressure in thehydraulic actuator (Mishchuk, 2018; Gao et al., 2020). The amplitude modulation will require more sophisticated executive equipment (Fan et al., 2017; Ouyang, et al., 2019). When using pulse-width modulation, the pressure to the hydraulic system is delivered in the form of impulses (the impulse shape is close to rectangular), and the effective pressure value is formed as a naturally established average.

Control systems operating with high modulation frequencies, are widely used in foreign practices (Lv et al., 2017; Huova et al., 2018; Zhang et al., 2020). It is proposed to implement control systems working within the frequency range of 5-15 Hz. Such frequencies allow directs impact on the compression force of the disk package and control of the slipping process. The indicated frequencies will allow the mechanical part of the package to work out the control law; the operating valve has a simpler design, is cheaper and less demanding to the level of oil purification. In addition, it becomes possible to work with long hydraulic lines - that is, to upgrade existing units containing friction control elements.

The traditional motion control system of tracked vehiclesis an open loop control system. The position of the control body, set by the driver, does not correspond unambiguously to the value of the turning radius. A closed-loop control system is practically devoid of disadvantage.

The closed-loop control systems for tracked vehicles' movement for the main tanks with the on-board gearboxes were developed in Russia (Lozin et al., 2019b; Volkova et al., 2019; Gen et al., 2020). The structure of the control system is shown in Fig. 1.

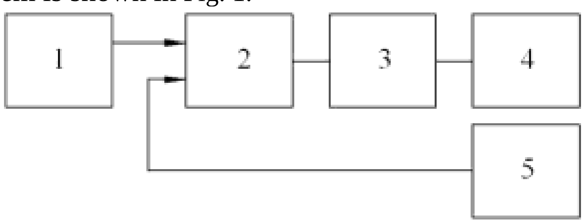

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Figure 1. The structure of the servo steering control system with the pulse-width modulation of pressure: 1 – master controller; 2 - differential amplifier; 3 – pulse-width modulator; 4 - control object (friction control element); 5 - feedback sensor

The main elements are: 1. master controller (connected to the control system), 2. differential amplifier, 3. pressure modulator, 4. actuator (solenoid valve in the friction control line); 5.feedback sensor.

In straight line motion, the signals of the master controller 1 and the feedback sensor 5 are equal. The differential amplifier generates zero voltage at the output and a signal with a zero duty ratio is sent to the pressure modulator 3. The electromagnet of the modulator 3 is deenergized, the converter inlet valve is in the "drain" position, the control element 4 is turned off.

The movement of the control member leads to the appearance of an error signal at the output of the differential amplifier 2. The duty ratio of the signal at the input of the modulator 3 becomes close or equal to 1 unit. The modulatorelectromagnet is turned on and puts the converter inlet valve in the "discharge" position. The hydraulic cylinder of the control member is turned on.

The machine enters a turn. The error signal from the amplifier 2 decreases, and the pulse duty ratio at the input of the modulator 3 decreases too. The modulator 3 starts working in the modulation mode and alternately connectsthe hydraulic cylinder to the drain or discharge lines. The system is in the dynamic equilibrium, and the controlled element will slip at a constant speed, making a turn with the preselected radius.

The control system of the described structure was used atSt. Petersburg Polytechnic University when working on the problem of the turn steering for military tracked vehicles. The purpose of the research is to improve controllability of trackedvehicles (and as a result, transport performance of the forest tracked vehicles) by controlling slipping discs of the friction control element.

Methods and Calculations

In the course of the study the following research was conducted: a design experiment (the stages of selecting the main mass-dimensional and energy parameters of the test bench, research work of control algorithms for the test object);an engineering experiment (launching, debugging and tuning of the stand; debugging of the operation of the control system components in test bench conditions and etc.).Theoretical methods (synthesis, abstraction, generalization, deduction, analogy, computer modeling) and empirical methods(description, comparison) were employed at various stages of the study.

The kinematic diagram of the test bench, developed at St. Petersburg Polytechnic University for the study of controlled slipping of disk clutches, (Yi et al., 2018) is shown in Fig. 2.

The gear system is started from a three-phase asynchronous electric motor 1 with the capacity of 125 kW at 1450 r/pm. The object of the test is the disk brake 5. When the brake is engaged, the oil from the tested pressure control system entersits booster.

To simulate the inertial mass of the chassis unit a flywheel 3with a variable moment of inertia is provided. Rotation onto the flywheel 3 is transmitted from the electric motor 1 througha permanently closed friction clutch 2. The reduction gear 4 is installed behind the flywheel 3 and serves to obtain specified slipping speeds. The frequency of the shaft rotation 6, of the brakes 5 can be adjusted in the range from 0 to 400 r/pm dueto slipping of the clutch 2.

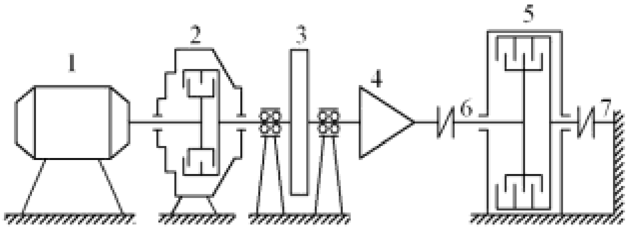

Figure 2. The kinematic diagram of the test bench for disk control and steering control system testing: 1 - electric motor; 2 - friction clutch for test bench loading; 3 - flywheel; 4 - reduction gear; 5 - tested disk control; 6 – reducer input clutchshaft 5; 7 - strain gauge shaft

The imitation of the change in the turning radius is reduced to the regulation of frequency of the shaft rotation 6 of the controlled brake 5. The instance, simulating the moment of resistance to the turn of the machine is created by the slipping clutch 2 through adjusted pilot pressure.

The test-bench conditions measure: travel values of the steering unit; pressure values in the hydraulic cylinder of the controlled brake; shaft speed of the controlled brake; brake torque 5.

The test-bench contains one controlled brake; therefore, there is no possibility to continuously examine the entire

extends from zero to a certain time. Consequently, the test modes were split into two sections according to the turning radii: first, from infinite to free radius (turning when the friction clutch of the rectilinear movement is controlled by controlled disabling); and second, from free to fixed radius (turning when the clutch is downshift). The control system's reaction to the steering control's many affects (stepwise movement, impulse effect, and manual monitoring of prescribed movement trajectory) was investigated in a number of tests. The effect on carrier frequency modulation control quality was examined at each test mode stage, ranging from 1... 2 Hz (lower limit) to the maximum level. Using the set depth of regulation, the testing was carried out by the regulating electro hydraulic unit.
Static features of the three control system alternatives (serial open-loop, modernised without feedback on the angular steering speed, and modernised closed-loop) were compared during running testing. The course that was used for the test runs was the same. We used potentiometric sensors to get the data on the location of the control components. We determined the discs' sliding speed using calculations based on information from speed sensors positioned at the steering mechanism's input and output shafts.
Figure 3 shows a comparison of the experimental control system's static properties with those of the fundamental control system.

Results and Discussions

The bench tests proved that the closed loop servo system using pulse-width modulation of the hydraulic system's pilot pressure achieves the most precise control of the hydraulic cylinder's pressure. Experimentally, the highest limit (with a regulatory depth of 0.1–0.9) did not go above 15 Hz in practice.
The experimental confirmation of the system's operation stability across the whole turning radius variation range and the revelation of the best operating modulation frequency range followed.
If you want better control over all factors while driving your machine with an onboard gearbox, use the discrete (tracking) servo steering control system. In comparison to the serial system, the proposed steering control system demonstrated absolute stability across all turning radii from infinity to fixed ones, a lag time for entering the turn that is three to five times less, improved stability of the vehicle entering the turn that is three to four times less, an amplitude of impacts on the steering control that is two to five times smaller when moving with large radii, and nearly full utilisation of the steering lever stroke for machine control. Modulation frequencies ranging from 8 to 15 Hz were used in the studies, with the exact range dependent on the sort of electromagnets utilised, and higher frequencies result in better steering control. The system's quality may be enhanced by using quicker electromagnets, which can raise the modulation's carrier frequency.
Figure 3 compares the experimental control system with the basic system in terms of static properties.

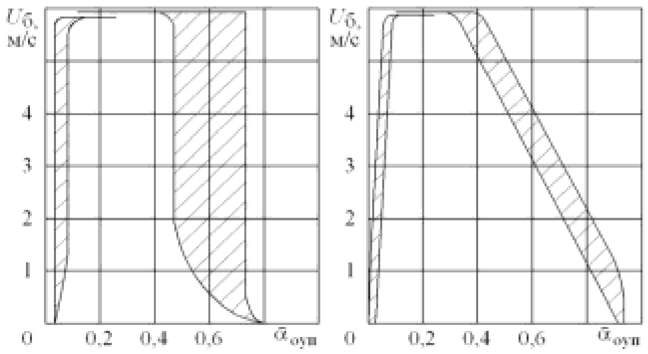

Figure 3. The static characteristic (dependence of the slipping speed of control disks in the gearbox in the position of the steering control element): for the serial steering controlsystem (to the left) and a prototype of the closed system (tothe right)

The discrete steering control system allows stable control of the disk slipping speed; its static characteristic shows that the speed of slipping monotonously changes under the steering control system movement.

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The above results show that the principle of controlled slipping can significantly increase the quality of the tracked vehicle steering. Comparative tests with machines equipped with multi-stream transmissions containing hydrostatictransmissions, an electromechanical steering mechanism (for example (Wu et al., 2019)) or multistage transmissions (Claus et al., 2020) have not been carried out. However, there is no doubt that technologies competing for quality insurance in steering are rather expensive, which makes their use in forest tracked vehicles problematic.

Since the disk type brake is the preferred object of pulse control in the tracked vehicle transmission system, the chassis upgrade will required replacement of the traditionally used “steering clutch” mechanism by the planetary steering gear.

Another example of solving the problem of “diagonal" steering control implementation is shown in Fig. 4.

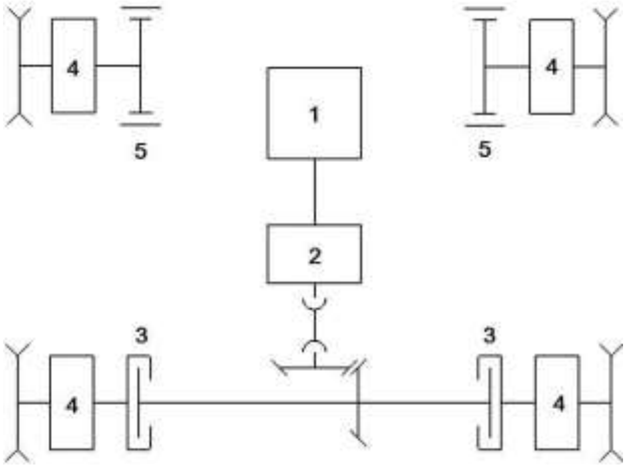

Figure 4. A streamlined implementation of the tracked vehicle's gearbox using "diagonal" steering control: 1) an internal combustion engine; 2) a gearbox and connecting gears; Thirdly, the steering clutch; Fourthly, the final drive (or final reduction gear); and Fifthly, the brakes.

What follows is the operation of the gearbox. For motion in a straight line, the power goes from engine 1 (the internal combustion engine) to the driving wheels via a gearbox that contains components that are commercially accessible. The gear rims-equipped tractor steering wheels are linked to the final driving gear 4 (or directly to) using
feel free to turn using the five brakes.
Making sure the steering clutch 3 linked to the trailing side slips is important to begin the turn with a radius bigger than a free radius. The machine goes into free turn mode when the steering clutch is not engaged. By using brake 5, the turning radius may be further reduced to the estimated minimum, which is half the track width. The trailing side's steering wheel is linked to the brake. When forces are applied to the chassis diagonal, it creates the turning moment.
Using this method, hydraulic drive multi-disc friction brake controls may be installed almost without removing the serial gearbox, enabling the use of pulse control technology for disc package slippage. If the machine has compliant tracks (with a rubber mount or without) mounted on it, the front-mounted brakes provide additional benefits, such as reducing the likelihood of track slippage on the rear drive wheel while stopping. The ability to recuperate power is an extra perk; in addition to the brake, the wheel may be linked to the generator, which produces the braking force needed to spin the machine with a radius less than its free radius.
Machine weight and chassis complexity will both rise with the use of the "diagonal" steering control technique. The new track tension mechanism has to be developed for this.

Conclusion

Thus, it is arguable that forestry and transport vehicles' operating qualities will be substantially enhanced when tracked vehicles are guided by a closed (tracking) control system. These control systems might be used more extensively in gearbox units and specialised machines built on tracked and wheeled tractor chassis, according to what seems appropriate.

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Based on the described principle of the "diagonal" control system, forest tracked vehicles can use it to steer their chassis with minimal interference to the serial transmission design. This allows for the development of conditions that are suitable for the implementation of pulse control steering technology, which has its roots in the transmission disc brakes of military tracked vehicles.
The quality of tracked vehicles' steering is greatly improved by controlling the sliding in the friction control components of the gearbox units. In addition, disc sliding may be directly controlled using the hydraulic drive's pulse-width modulation of pressure at low frequencies (5–15 Hz).
Tracked cars' movement control systems may include the sliding control concept from braking control components into steering control systems. Planning the system's prototype testing on the improved skidder chassis should be considered in future research.
A steering control system prototype and an experimental stand were built from technical drawings. The stand may serve as a teaching tool in its current state. Using the stand to simulate a tracked vehicle's steering control system doesn't need major adjustments.

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