Safety Mechanism in Sawing Machines Based on a Preventive Detection of Human Tissue

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***Abstract*—Accidents with band saws are the second most main reason for injuries in carpenter's workshops. Therefore, an actuation system shall be developed, which creates a safe state, after a signal is provided by a preventive sensing system. The main goal is to provide a system, which is capable of creating a safe state of the saw. Furthermore is should be suitable for series production. The chosen working principle is to brake the saw band to a standstill. The fundamentals are investigated for two subsystems: A mechanism to decouple the blade from the flywheels and a nitinol actuator for the brake. It is shown, that the force transmission from the blade to the flywheels can be reduced to a fraction within tens of milliseconds. Furthermore, it is shown a nitinol actuator can apply several kilo Newtons, while having an almost immediate response.**

***Index Terms*—Band saw, safety system, nitinol actuator**

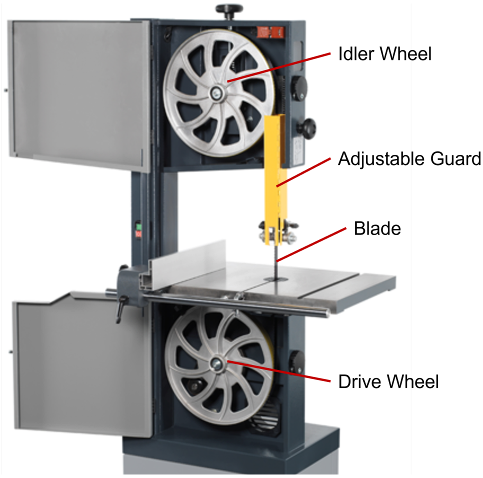

Fig. 1. Basic setup of a band saw

I. Introduction

MANY injuries in carpentries are caused by band saws. Companies specialized in automation, developed safety systems, which are optimized for meat processing or heavy industry, but are not suitable for wood working. A key component to such a system is its actuation, which creates a safe state of the machine within a very short time span.

The basic setup of band saws can be seen in figure 1. A closed loop saw band runs around two rotating wheels. The lower wheel, also called drive wheel, is powered by an electric motor, while the upper wheel (idler wheel) is passively moved via force transmission of the saw blade.

To ensure a good cutting result, the blade is tensioned. Therefore, a spring pushes the idler wheel upwards. The movement is limited by the blade, which causes the blade tension. Band saw developers recommend blade tensions of 60 to 80 MPa.

In literature, three realized solutions for band saw safety systems can be found: Guardian Band Saw and Scott Automation from the meat industry and a scientific research by Portland State University.

According to the patent of Guardian [1], the actuation of the first one works with a detensioning mechanism for the saw blade, so that the blade can slip on the wheels, and the blade can be stopped, while the heavy wheels are still turning. This reduction of inertia decreases the breaking time drastically.

The break itself is solved with an always-on solenoid, which compensates a spring force in normal use. In emergency it is switched off and the spring presses the break shoe of a wedge break onto the blade. The system requires 24 ms to stop the blade.

The system of Scott Automation also reduces the mass, which has to be braked, by detensioning the blade [2]. Unlike Guardian they use a hydraulic braking system [3]. Its stopping time is specified with 15 ms, including the required time of the sensor [4].

A third working safety system was built by Portland State University [5], which has in contrast to the previously mentioned solutions no detensioning system. It stops the blade with a spring powered wedge brake, which is held back by a steel wire, that is burnt electrically in case of emergency. A major issue created by the wedge brake approach is the dependency on clean blade surfaces. In the optimal case the braking time is 15ms, while an oil contaminated saw blade can take up to 75 ms, due the reduced self-reinforcing effect of the wedge brake. Furthermore this solution is not commercially available and was only built for a scientific project.

In the present paper is investigated, how a reliable and cost efficient solution for the actuation of a band saw emergency system could look like. This includes first of all the development and selection of a general working principle. Furthermore, the key elements of this working principle shall be further investigated. This includes the development and tests of key components, which then shall clarify the feasibility of the approach and point out key challenges for the further development.

First the methods are explained including the finding of a general working principle and the development of key components. Then test results for prototypes of these components are presented. The results of the tests are then shown and discussed. A conclusion gives a concise overview of the paper.

II. Methods

The general working principle chosen for the project, is to stop the blade when an endangerment is detected, so that a contact between operator and the blade does not lead to serious injuries. A subsystem referred to as decoupling mechanism is used, to cut off the force transmission between the blade and the flywheels. This reduces the mass, that has to be slowed down and with that the inertia of the system. A brake as a second subsystem is applied to the saw band, which shall be stopped within the order of a few milliseconds.

A. Decoupling Mechanism

The decoupling mechanism is developed as a redesign of the original tensioning system and can be seen in figure 2.

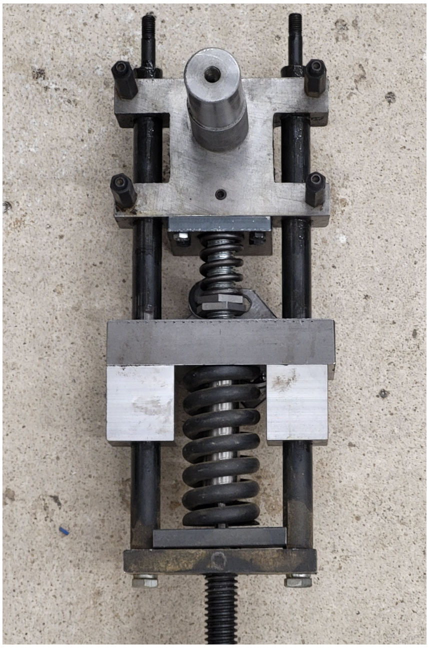

Fig. 2. Prototype of the decoupling mechanism

A main difference is a leaver, which can directly transmit the force, from the original tensioning spring to the wheel support, in its upright position (state one). When it is tilted (state two), a more compliant second spring is interconnected between the original spring and the wheel support. With that, less force is applied to the wheel support and the blade's tensioned is reduced.

It is considered important, that the blade is not fully untensioned, since this could cause oscillations. Instead a minimum tension shall be kept, which is the reason why there is a second spring. The remaining force after the actuation can be adjusted with to nuts on the spring support. It is recommended to keep a minimum tension of 15 MPa.

To reduce the required force during an actuation, the lever is fixated with a bearing to its support, like shown in figure 3. Furthermore, a bearing is placed at the free end of the lever, where it contacts the wheel support. The reduced friction also improves the mechanisms performance, since it allows a faster tilting of the lever.

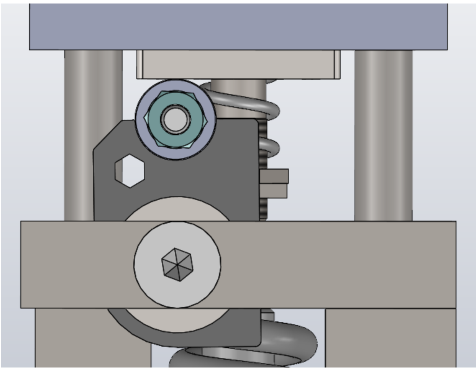

Fig. 3. Lever of the decoupling mechanism in its upright position

Since the evaluation of the mechanism focuses on the reaction of the blades tension, only a manual approach was implemented. As a result, the lever's movement has to be initiated by pushing a rod against it. To reset the mechanism to its first state, an Allen key can be used as an extension of the lever. Therefore, the corresponding counterpart is laser cut into the lever.

The mechanism's tests are performed in stand still of the machine, to enable tension measurements of the blade. To get the blades tension, a strain gauge is attached to the blade. With a Wheatstone bridge, the gauges resistance change is measured. Since the strain gauges are not calibrated, only the relative changes can be measured, while the offset is unknown. To determine said offset, the eigenfrequency of the blade is measured before the actuation, so that the tension can be calculated. With this result, the measurements of the strain gauges can be adjusted.

B. Brake Actuator

The second investigated subsystem is the nitinol actuator for the brake. It shall be capable of applying a force of 3,670 N. Furthermore it shall have a maximum stroke of 0.5 mm, while the initial strain of the wire shall not exceed 4%. The maximum allowed tension of the wire is limited to 350 MPa to prevent fatigue. To prevent unwanted triggers in warmer environments, the wire's A_s temperature shall be at 80°C.

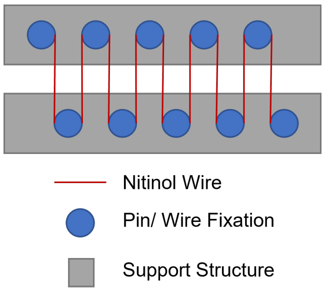

Fig. 4. Basic setup of a nitinol actuator

A sketch of the basic actuator design can be seen in figure 4. Its basic working principle is intended to be as follows: First, the wires are electrically energized. Via Joule heating, the wires temperature increases above the A_s temperature, which initiates a phase transformation in the wires. The resulting contraction of the wires leads to a movement of the actuator, which is limited by an obstacle. This results in a force. As long as the wire's temperature is above the M_s temperature, the actuator applies a force.

Since the structure as well as the pins for the wire fixation are made of steel for a maximum stiffness, they must be electrically isolated, to prevent a short circuit. Therefore, the pins are mounted into a polycarbonate support like shown in figure 5. Furthermore, the wire must be separated from the steel structure with a layer of isolating material. To avoid a too high bending load in the plastic support, the pins are fixated on both sides, like shown in the aforementioned image.

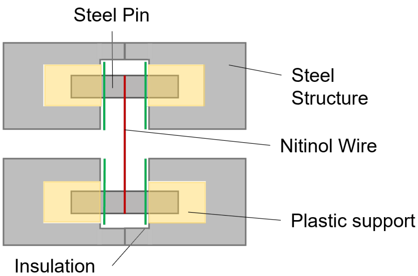

Fig. 5. Sectional view of the wire's fixation

An important factor for the actuators performance is the utilized wire. It has a thickness of 0.5 mm and is purchased from the Nexmetal Corporation. It has an A_s temperature of 80°C with a variation of ±10 K. Furthermore, the A_f temperature is expected to be 130°C. With this data, 54 wire sections like shown in figure 4 are required to build up the required force, while keeping the tension below 350 MPa. Said sections have a length of 27 mm, which gives a maximum stroke of 1.08 mm without exceeding the strain of 4%. The prototype of the actuator is shown in figure 6.

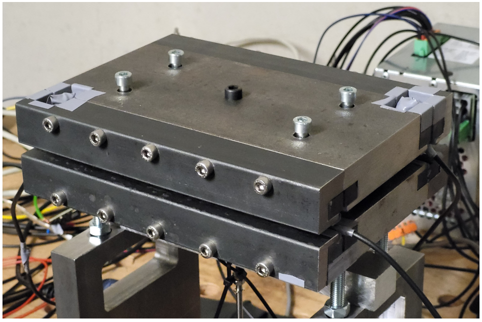

Fig. 6. Prototype of the brake actuator

During the tests, the actuator is powered by a capacitor bank, which can provide up to 420 J at 800 V. The test bench itself can be seen in figure 7.

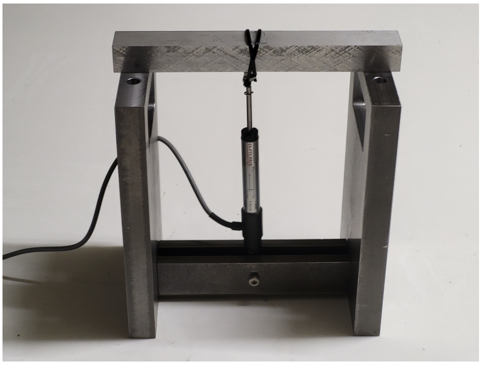

Fig. 7. Test bench for the actuator, including the force sensor

It has drilled holes for the fixation of the actuator and provides a sensor for the measurement of the applied force. Therefore, an aluminum beam is elastically deformed by the actuators force. It can be seen of top of the structure. The resulting deflection is measured by a linear potentiometer, which gives information about the actuators force. The required force for one millimeter deflection is 16.9 kN/mm. Furthermore, the voltage and and the current applied to the actuator are monitored.

Since temperature has a high influence on the behaviour of nitinol, it is important to mention, that the temperature of the testing site was constant at 26°C.

III. Results

A. Decoupling Mechanism

The tension's development for a saw blade with a width of 16 mm is shown in figure 8. The average tension of the ten performed measurements starts to decay 4.5 ms after the trigger. The final tension of 15 MPa is reached 32 ms after the trigger. Afterwards, the tension oscillates with about ±5 MPa around the final tension.

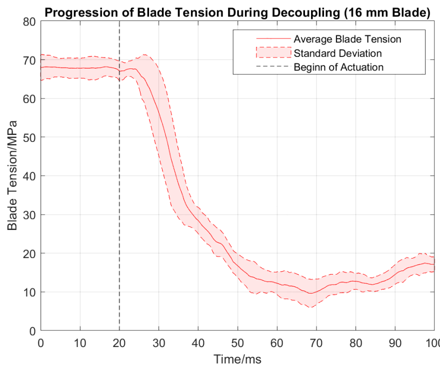

Fig. 8. Tension development of a 16 mm blade during the decoupling

This tension reduction reduces also the force transmission from the blade to the flywheels, so that the stopping time of the mechanism is reduced. The oscillation of the tension in the end of the measurements are considered to be no problem, since at this time the blade should already be stopped, so that the blade will not start moving off track, due to too low tension.

The cost efficient design of the mechanism, with as few new parts as possible, causes stick-slip-effects of the tensioning system during the adjustment of the blades tension. An important cause for that are the plain bearings of all linearly movable parts. Because of limited space, the springs and the lever are not on one line, so that they create a moment, that further increases the friction of the bearings. Although this makes the tension adjustment a process of trial-and-error, it has no significant effect on the final tension of the decoupling as well as the resetting of the mechanism. In both cases the spread of the tension is low.

B. Brake actuator

A fast response of the brake actuator is crucial, when stopping the blade in a short amount of time. When evaluating the time-force behaviour, the force must always be evaluated in the context of the energy introduced into the actuator. The force and energy progress of a measurement with 180 J final energy is depicted in figure 9. Both quantities are normalized to 100% of their final value.

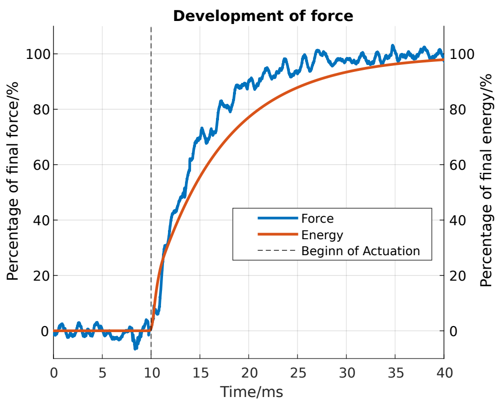

Fig. 9. Normalized development of the actuators force and the introduced energy

When the energy starts to rise, the force has only a slight delay, which can not be further quantified, due to the noise of the sensor. Fifty percent of the final force is reached 3.3 ms after the actuation, with

45% of the energy. Until 90% of the force is applied, it takes about 11 ms and 80% of the energy. 25 ms after the trigger 100% of the force is reached, with 96% of the energy.

That the force rises almost immediately, as soon as the energizing starts, seems paradox, since calculations show, that 45 J are required to reach the A_s temperature. This corresponds to 25% energy in figure 9. A possible explanation for this behaviour is that the wire is not heated evenly, instead some parts are heated significantly stronger than others. Reasons for that could be geometrical imperfections like a locally reduced cross section or impurities of the material, which increase the local resistance. Such an effect would have a high impact, when the power is high, like in the beginning of the actuation. When the power is much lower in the end, the thermal conductivity compensates these effects. It is recommended to investigate, what exactly causes this behaviour, and how it can be realized in a stable process for a serial product, since the premature actuation, enables the safety mechanism to stop the blade even faster.

A further important factor is how much force is applied at different energies. Figure 10 shows that the force increases rapidly at lower energies. The growth flattens, the more energy is introduced into the actuator.

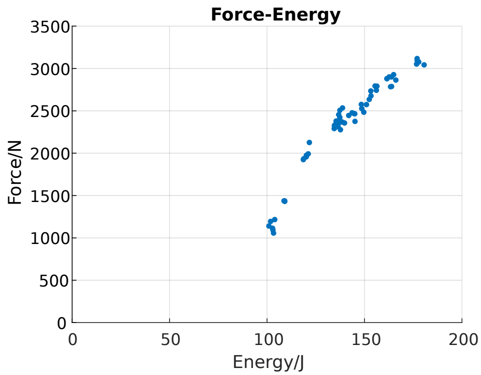

Fig. 10. Maximum actuator force for different input energies

While the force is about 1100 N, when the energy is slightly above 100 J, it rises up to 3,117 N when 177 J are introduced. Nonetheless, this is still 15% lower than the 3,670 N aimed for.

Calculations say, that 92 J are necessary to heat the wire from the temperature of the testing site up to the specified A_f temperature of 130 °C. This seems to contradict with the measurements in figure 10, where the force increases although the energy is beyond 92 J. This is caused by a stress induced shift of the transformation temperatures, which means that the nitinols phase transformation requires higher temperatures if stress is applied. Sources have no clear result for the magnitude of this shift [6] [7].

When dividing the final force by the introduced energy, the measurements with a lower energy have a lower efficiency. This is caused by the difference between the temperature at the testing site and the wires A_s temperature, which requires 45 J to be compensated, like mentioned previously.

IV. Conclusion

This research's goal was to provide a concept for creating a safe state of band saws within milliseconds. As a basic working principle this thesis suggests to stop the saw blade. Therefore, a decoupling mechanism reduces the saw bands tension, which also reduces the force transmission to the wheels, so that less mass has to be stopped. Furthermore a brake is directly applied to the blade.

The decoupling mechanism's works with a leaver, which can directly transmit the force from the tensioning system to the wheel support in its upright position. When it is tilted, a weak second spring is interconnected, which applies less force to the wheel support, so that the blade's tensioned is reduced.

Tests showed, that the system can lower the blade tension to a fraction of the initial value in the range of 30 ms. After reaching the tension aimed for, the tension slightly oscillates. For the safety mechanism this improves the performance, since less braking force is lost to the wheels, and the blade can be stopped more effectively.

For the brake actuator nitinol was selected as working principle. The prototype consists of two plates, which are connected with nitinol wires. When the wires are energized, they heat up and contract, so that a force is applied.

The test results show, that the actuator responds almost immediately, and that the time until the final force is reached is mainly limited by the accessible power for the heating. Furthermore the actuator applies a force of 3.1 kN, when introducing 180 J. This is 15% lower than the required force.

Both concepts of the subsystems are considered, to be suitable for the safety mechanism. Nonetheless, further development is necessary until they are ready for serial production. Furthermore many other components need to be developed for a fully functioning actuation of a band saw safety system.

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