Pneumatic Trigger Redesign

Senior Design Proposal submitted to the
Department of Mechanical and Materials Engineering
College of Engineering and Applied Science
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In Partial Fulfillment of the
Requirements for the Degree of

Bachelor of Science

in Mechanical Engineering Technology

by

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Problem Statement

Per a new and upcoming European regulation on non-electric handheld tools the project would require a newly designed trigger and remote to meet regulation. This trigger would feature a time-out system that can revert the tool from one firing mode (Bump Fire) to another (Single Sequential) if depressed for a predetermined amount of time. This would in turn require the remote to have a dual input valve to accomplish the previous. Combining both of these unique features benefits the tool by preventing unsafe conditions, reducing moving parts inside the trigger mechanism, and reducing the complications when using an inner trigger component. This project would create a possible solution to the previously stated problems that meets all patent and ISO requirements.

Research

Problem Background

New and upcoming regulations in Europe will require all pneumatic handheld tools to have a trigger time-out mechanism that will disable the firing mechanism after a period of inactivity while the trigger is pulled. SENCO patented a time-out mechanism in pneumatic tools as far back as 1975. They have also patented mechanically controlled safety mechanisms, electronically controlled safety mechanisms, and a tool that would be best described as a hybrid (electrical/mechanical) with enhanced safety features called Think-Trac (8) (11). Some of these concepts were brought to market while others did not move past the development stage. The patents listed below in the sources would be considered prior art, thus allowing the proposed tool to be freely commercialized without the risk of violating a competitor's solution.

The primary group affected by the lack of an adequate safety measure is the consumer who will not be able to procure the tools that they need for their jobs, such as framing and brad nailers and staplers. In addition to the consumers affected by not being able to purchase tools, Kyocera Senco will not be able to serve the European market due to not meeting the updated ISO 11148-13:2017 that regulates handheld non-electric power tools.

While the regulation mentioned previously is not currently implemented in the European market, the problem impacts the safety of the tool and the finances of Senco and its customers. Without a redesign to the trigger and remote, future pneumatic tools from Senco would not be allowed to be sold in Europe until the tools were compliant with the regulations of non-electric handheld tools.

Listed below in the Works Cited section are a series of patents from several companies that feature a time-out trigger or a dual action valve. For our project, the design must not infringe on any of these documented designs while still meeting the requirements of the upcoming European regulation.

The current solutions provided in the market, as seen in the competitor patents, either integrate a time-out or a means to revert from one mode (Bump Fire) to an alternate mode (Single Sequential) were initiated as the pneumatic fastener tool standard ISO 11148-13:2017 was being considered (2). The gap that we will be filling is to produce a solution that integrates both features into the existing body of the tool, without having to redesign or move any current components within the tool. This senior design project will allow SENCO to produce and sell compliant tooling in the European markets, where they otherwise would not, with the upcoming regulations to be put in place.

Applicable Standards

The redesigned trigger and firing mechanism must adhere to ISO-11148-13, which is intended to increase the safety of handheld, nonelectric power tools. The proposed standard plans to implement a safety feature that will disable the firing mechanism if the trigger is depressed, and a fastener is not driven within a period of one to five seconds. The new mechanism will require the trigger to be released and depressed again after an idle period of being depressed to eliminate the chances of a negligent discharge when the nose is depressed, and the trigger is left depressed. The scope of ISO-11148-13 includes pneumatic and combustible gas-driven fastener driving tools and does not apply to hydraulic or electrically powered tools (2).

To ensure structural integrity and a robust design, the tool must adhere to ANSI SNT-101-2015 standards. This standard stipulates two factors of safety, one for the pressure bearing vessel, and one for the internal parts. The empty tool body must withstand 5x the maximum stated pressure for the tool without rupturing. The fully assembled tool must be pressurized to 1.5x the maximum stated pressure or 1.38 MPa, whichever is higher, for two minutes without self-actuating, firing a fastener.

State of the Art

Currently, there are essentially two variations of state-of-the-art designs concerning the firing control of pneumatic fastener driving tools, ISO-11148-13 compliant tools and their prior art, ISO-11148-13 non-compliant tools.

With non-compliant tools, i.e., tools that do not contain a timeout system in the trigger or firing mechanism, the manual of arms are like what is described in US Patent 3278106A, *firing control means*, which describes a "safety member" that must be depressed against the workpiece with the trigger depressed simultaneously to fire a fastener (16). Another variation, described in US Patent 5522532A, *Single-shooting/continuous-shooting control switch for pneumatic nail guns*, which describes a selector switch, allowing users to change from predetermined modes, one for "single shooting," that allows only one fastener to be fired with each trigger pull, and a mode for "continuous-shooting," commonly known as bump firing, where the trigger can be depressed and the tool only requires the nosepiece to be depressed to fire a nail, allowing for faster operation within a production environment (17). US5522532A uses a system of valves and valve rods to control a hard stop on the contact actuator to change from mode to mode. While these tools allow for fast operation, they sacrifice safety by allowing inadvertent firing if the trigger remains depressed and the nosepiece or contact tip are depressed against any surface, including skin.

These examples do not constantly provide the ISO-11148-13 compliant mechanism that will disable the firing mechanism after a set period and provide no method of mitigating negligent discharges from contact action and only provide protection from contact discharges in one mode, respectively.

State of the art potentially ISO-11148-13 compliant firing mechanisms include US 3964659A, which includes a device known as the "remote valve assembly" and "timing valve assembly" that set a time limit on inactivity of the firing mechanism. This system required the firing mechanism to be initiated again if either the nosepiece actuator or trigger were engaged for a predetermined period without firing (1). The language used in US 3964659A is vague in its description of the time-out device's operation, mentioning that it could use "cams, levers, or linkages, various combinations of valves," among other mechanisms and "may be actuated pneumatically, mechanically, magnetically, or by other appropriate means" (1). US 3964659A had an anticipated expiration in 1993 and is now expired. Another method to manage the firing rate is US 9662776B2, which uses a damper in the trigger mechanism to control movement of the actuation lever within the trigger mechanism that will disable the firing mechanism by blocking the movement of the actuation lever when a predetermined time has passed (19).

The next state-of-the-art design is not a released product but is described in the patent EP3263284A2, Firing Control Device for a Pneumatic Tool, from Basso Ind Corp. Their patent goes into detail on two different safety mechanisms: the first is in the trigger, where if the trigger is continuously depressed without the depression of the safety member, the switch valve is activated causing there to be no airflow to the connecting passages and main cylinder (6). Since the valve rod is still in the non-activated position, the main cylinder cannot be filled, which will not allow the tool to fire a fastener. Next, there was the implementation of a dual safety feature, where when firing a fastener, the time delay between the depression of the remote and safety member must be less than the defined time out. If it is less the valve rod is activated when the trigger is depressed the bypass airflow channel will be blocked allowing airflow to enter the main cylinder (6). This air that enters the main cylinder has a different pressure than inside the chamber allowing the firing value to be retracted airflow to enter the chamber, and the fastener to be fired (6). This is expanded upon by stating that the trigger assembly can be forcibly released by the switch valve back to a non-activated position. This can be done by a stationary part that allows or halts the airflow between two connecting passages (6). When reverting the trigger to a non-activated position this part prevents airflow from connecting via the passages and the main chamber. By doing this the trigger is forcibly reset to a non-activated position and is ready for the next input by the operator (6).

The state of the art for the pneumatics of the entire tool isn't pointed at one specific brand or tool. The overarching design of how these tools work is such an old design that is used by so many, that it is difficult to pick out just one.

There are two states of the art designs for a trigger design on pneumatic tooling. One of which is a tool designed by Senco over 28 years ago called the Think-Trac, which incorporated a battery pack that powered a microprocessor (8). That microprocessor would automatically detect the firing mode in which the tool was being used and implement a time limit on the trigger, safety member, or both. This was an external feature that was implemented as an addition to a tool but required the use of AA batteries, drawing into question the true meaning of a pneumatic tool (10). This tool addition was designed to add increased safety to the tool without having to modify tools. This addition, however, was not popular in the market as the tool was pneumatic but the additional safety required batteries to be powered. This led to twenty tools being produced but none of the said tools being sold to customers.

Applicable Patents

- US 3,964,659 A1
    - This is a patent published in 1976 from Senco. This patent is specifically referring to the ThinkTrac tool introduced to initially solve accidental discharges in the field due to the trigger being depressed. Key details from this patent that can aid in our design parameters are the following:

    - Firing control means comprising two separate and independent triggering means shiftable independently and in any order between normal and firing positions and requiring both triggering means to be concurrently in their firing positions to actuate the tool.
    - Actuation of the other previously released triggering means so that both triggering means are in the firing position within the time limit, will fire the tool. Actuation of the other previously released triggering means after the time limit, so that both triggering means are not concurrently in their firing positions within the time limit, will not fire the tool. The time limit is reset by releasing the manual trigger (if the trigger only starts the time limit), by release of the workpiece responsive trip (if the trip only starts the time limit), or by releasing both the manual trigger and the workpiece responsive trip (if either triggering means will initiate the time limit).
    - Manually actuated trigger valve assembly 210 and timing valve 225 is provided with a metering orifice 231. The metering orifice 231 regulates the passage of air from annular notch 211 to the timing valve 225. In this way, metering orifice 231 serves substantially the same purpose as metering orifice 117 in FIGS. 10 and 11, for example. That is, metering orifice 231 determines the duration of the time delay.

- US 6,604,664 B2
    - This is a patent published in 2003 from Illinois Tool Works Inc. and details a time delay feature for pneumatic driving tools. Key notes and areas of their design are the following:
    - The present invention relates generally to pneumatic fastener driving tools, and more particularly to a new and improved pneumatic fastener driving tool wherein the tool has incorporated therein a control system which ensures the safe operation of the tool while effectively permitting the operation of the tool within either one of two rapid fire modes.

    - Accordingly, a need exists in the art for a new and improved pneumatic fastener driving tool wherein the trigger and workpiece contact elements are not required to be depressed or actuated in a particular manner or order whereby the tool is able to be operated in both high-speed bump-fire and trigger-fire modes of operation, and yet, the tool is also able to be operated in a safe manner so as to prevent the inadvertent, accidental, or unintentional discharge or firing of the tool despite the fact that an operator may carry or transport the tool between different worksites with the trigger element constantly depressed.
    - The reservoir tank is in turn fluidically connected to an enable valve assembly so as to provide signal air thereto, and a trigger element or mechanism is operatively connected to the pilot valve assembly as well as to a relief valve assembly. Accordingly, and initially, when the workpiece contacting element is engaged with a workpiece prior to the depression of the tool trigger element or mechanism, the compressed air is permitted to enter the reservoir tank through means of the fill valve so as to provide the reservoir tank with pressurized reservoir air, the pressurized reservoir air maintains the relief valve assembly closed and is also conducted to the enable valve assembly by means of a signal line, and the compressed air also pressurizes the main valve through means of the pilot valve assembly and the enable valve assembly. Upon subsequent depression of the trigger element or mechanism, the pilot valve assembly is opened, the pressurized reservoir air maintains the relief valve assembly closed against the biasing force of the trigger element or mechanism, and the air signal from the reservoir tank to the enable valve assembly maintains the enable valve assembly opened such that the main valve is able to be vented through means of the enable valve assembly and the pilot valve assembly whereby a fastener is able to be fired or discharged.

- 10,335,936 B2 by Basso Industry Corp
    - A firing control device for use in a pneumatic tool includes a flow path unit, a conditioning valve and a switch valve. The flow path unit is connected to a main. chamber and an operating chamber of the pneumatic tool. The conditioning valve blocks fluid communication between the main chamber and the operating chamber via the flow path unit. When the switch valve is activated, the pressure in the casing is permitted to move the conditioning valve. The conditioning valve is moved to permit the fluid communication between the main chamber and the operating chamber via the flow path unit when the switch valve is continuously activated by a predetermined time period.
    - (29) When the switch valve 51 is at the non-activated position, one of the switch sealing rings 512 is in air-tight contact with the second additional inner surrounding surface of the casing seat 20…
    - (30) When the switch valve 51 is at the activated position upon the depression of the trigger assembly 15 (see FIG. 4), the one of the switches sealing rings 512 is separated from the second additional inner surrounding surface of the casing seat 20 that defines the second shrunk section 205, and the other one of the switch

sealing rings 512 is in air-tight contact with the first additional inner surrounding surface of the casing seat 20…

- (34) Referring to FIGS. 4 to 6, when the trigger assembly 15 is continuously depressed without depression of the safety member 14, the switch valve 51 is moved to the activated position, so that the connecting passage 23 is not in fluid communication with the outside and is in fluid communication with the one of the main chambers and the operating chamber 12 that is in fluid communication with the throttle valve unit 4.

- *5,522,532 A*, Safe trigger with time delay for pneumatic fastener driving tools, Illinois Tool Works Inc
  - "The present invention has been accomplished under the circumstances, It is therefore the major object of the present invention to provide a single-shooting/continuous-shooting control switch- for pneumatic nail guns which can be conveniently controlled to set the mode of the nail gun for a single shooting or a continuous shooting alternatively."
  - "[Control] switch comprises two air valve seats linked between the pneumatic pressure source and the firing pin, and two valve rods moved by the trigger of the pneumatic gun to lift the valve rods in controlling the passage between the pneumatic pressure source and the firing pin, and a stop block turned about one valve rod to let the trigger lift one valve rod or both valve rods for a continuous shooting."

- EP2767365B1, *Compressed air nail gun with a manually actuated trigger and a contact sensor*, Joh Friedrich Behrens AG
  - The activation of the first control valve can trigger a drive-in process. This is done in the invention when the locking piston is in its rest position. On the other hand, when the blocking piston is in its blocking position, the triggering of a driving-in process is prevented when the first control valve is activated.
    In the invention, a second control valve is actuated upon actuation of the manually actuatable trigger independently of an actuation of the Aufsetzfühlers. The second control valve is thus activated with each actuation of the trigger. For this purpose, for example, a control pin of the second control valve may be arranged so that it is displaced from its rest position with each actuation of the trigger.
    In such a control of the second control valve, a chamber is vented via a throttle or vented. By "venting" is always meant that a connection is made to a compressed air leading room. By "venting" is always meant that a connection to a non-pressurized space, in particular to the outside air, is produced.
  - Therefore, in the invention, a driving operation after actuation of the trigger can be triggered only as long as the pressure in the chamber has not yet passed the predetermined pressure threshold.

- In any case, the above-mentioned embodiment means that the desired pressure, which corresponds to an initial state of the pneumatic nailer, is established in the chamber when the trigger is not actuated.

End User

The end users include European workers who plan to use pneumatically driven fastener driving tools and must-have tools compliant with ISO 11148-13. The primary industries that are affected are carpentry and roofing, but professions involving furniture building and upholstery will need compliant tools. The consumer and hobbyist market will also be affected, although amateurs would be as well served by tools that do not have the ‘bump fire’ or ‘sequential fire’ feature, which would render the tools as safe as ISO 11148-13 compliant tools but may not provide the rate of fire required in a production or commercial environment.

The current results from surveyed end users show that out of our five main categories, safety, ease of use, and little to no change in usability from current tooling were the top three items that the end user wanted out of this project.

Summary of Research

Due to the future implementation of the revised ISO 11148-13 standard, a new trigger design is necessary to allow Senco to sell and distribute its tools in the European market. This standard is intended to increase the safe operations of pneumatic tools. The two state-of-the-art designs are not currently in production and have specific design characteristics that make them difficult to implement onto current tools. Reducing or eliminating changes to main body castings is ideal, as any changes to castings will be expensive and require extensive research and development. The implementation of a compliant design without the need to develop and manufacture new tooling will more quickly accommodate the needs of end users affected by ISO 11148-13.

Quality Function Deployment

Based on a survey conducted on September 1st, 2022, through international customers, the following items were marked as the highest priority; safety, reliability, ease of use, and responsiveness. These priorities are based on forty international customers’ responses. A sample survey has been included below.

Survey Sample

Hi, my name is Laurence Bushley, a University of Cincinnati Mechanical Engineering student. I worked two rotations at Kyocera Senco and have been tasked with redesigning the remote and trigger to meet upcoming ISO regulations for European non-electric handheld tools. Please answer the following survey questions to help gauge what matters most to you.

Answer 1 - 5 in order of importance; 1 being least and 5 being most important

How important is each feature to you?

Safety (5)

Reliability (5)

Ease of Use (4)

Responsiveness (4)

Size (2)

Ergonomics/Design (3)

Speed (5)

Answer 1 to 5 in order of satisfaction; 1 being least and 5 being most satisfied

How satisfied are you with the current trigger system (restrictive or dual action)?

Safety (4)

Reliability (3)

Ease of Use (5)

Responsiveness (4)

Size (5)

Ergonomics/Design (4)

Speed (3)

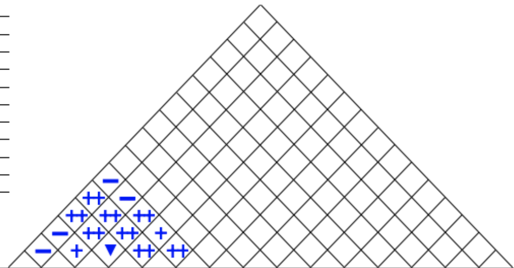
House of Quality

Title: House of Quality for Pneumatic Trigger Redesign

Author: L. Bushley, L. Guessford, and E. Koczwara

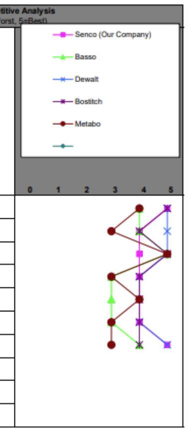
Date: 9/16/2022

Notes:



Row #	Max Relationship Value in Row	Relative Weight	Weight / Importance	Demanded Quality (a.k.a. "Customer Requirements" or "Whats") \ Quality Characteristics (a.k.a. "Functional Requirements" or "Hows")	1 Assembly Volume	2 Manufacturability	3 Variable Pressure Compatibility	4 Simplistic Design	5 Internal / External Design	6 Multiple Tool-Line Compatibility	7	8	9	10	11	12	13	14	15	Senco (Our Company)	Basso	Dewalt	Bostitch	Metabo	
				Direction of Improvement: Minimize (▼), Maximize (▲), or Target (x)																					
1	9	15.5	167.0	Safety	▲	▲	Θ	▲	O	▲										5	4	5	5	4	
2	9	14.6	158.0	Reliability	▲	▲	O	▲	Θ	O										4	4	5	4	3	
3	9	15.3	165.0	Ease of Use	▲	▲	Θ	O	▲	O										4	5	5	5	5	
4	3	15.1	163.0	Responsivness	▲	▲	O	▲	▲	▲										4	3	4	4	3	
5	9	11.8	127.0	Size	Θ	O	▲	Θ	▲	▲										4	3	4	4	4	
6	9	12.9	139.0	Ergonomics/Design	O	Θ	O	Θ	▲	Θ										4	3	4	4	3	
7	9	14.8	160.0	Speed	▲	▲	Θ	▲	▲	O										5	4	5	4	3	
8																									
9																									
10																									

Competitive Analysis (0=Worst, 5=Best)



Column #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Target or Limit Value															
Difficulty (0=Easy to Accomplish, 10=Extremely Difficult)	10	7	8	5	4	7									
Max Relationship Value in Column	9	9	9	9	9	9									
Weight / Importance	219.9	226.6	550.0	327.8	248.1	292.6									
Relative Weight	11.8	12.1	29.5	17.6	13.3	15.7									

Legend

Θ	Strong Relationship	9
O	Moderate Relationship	3
▲	Weak Relationship	1
++	Strong Positive Correlation	
+	Positive Correlation	
−	Negative Correlation	
▼	Strong Negative Correlation	
▼	Objective Is To Minimize	
▲	Objective Is To Maximize	
x	Objective Is To Hit Target	

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Product Objectives

Safety (15.5%)

To ensure the safety of the customers that will be operating this tool, the safety member must not be able to be tampered with in any way creating an unsafe environment. Additionally, the remote must be tamper-proof, to ensure that end users will not be able to modify or defeat the safety devices. This may include but is not limited to safety valves that allow airflow to be redirected if the tool 'senses' an unsafe environment.

Reliability (14.6%)

The reliability of the tools must not be affected by new triggers and remote mechanisms. All tools fitted with new triggers and remotes should keep the same service life and should be serviceable by users and authorized repair centers.

Ease of Use (15.3%)

The trigger should be as easy to use as a trigger on a normal tool. No additional pull force on the trigger or extra steps should be needed to activate, outside the required safety features.

Responsiveness (15.1%)

The tool must still function as well as a tool without this trigger, not impeding the resetting of the trigger or firing of fasteners. The tools should retain their sensitivity on the nose and trigger, and both should keep the same actuation force.

Size (11.8%)

The design should be but is not limited to, the size of the standard remote. The primary goal is to provide a proof of concept for an ISO-compliant system, not a solution that is ready to be brought to market immediately.

Ergonomics/Design (12.9%)

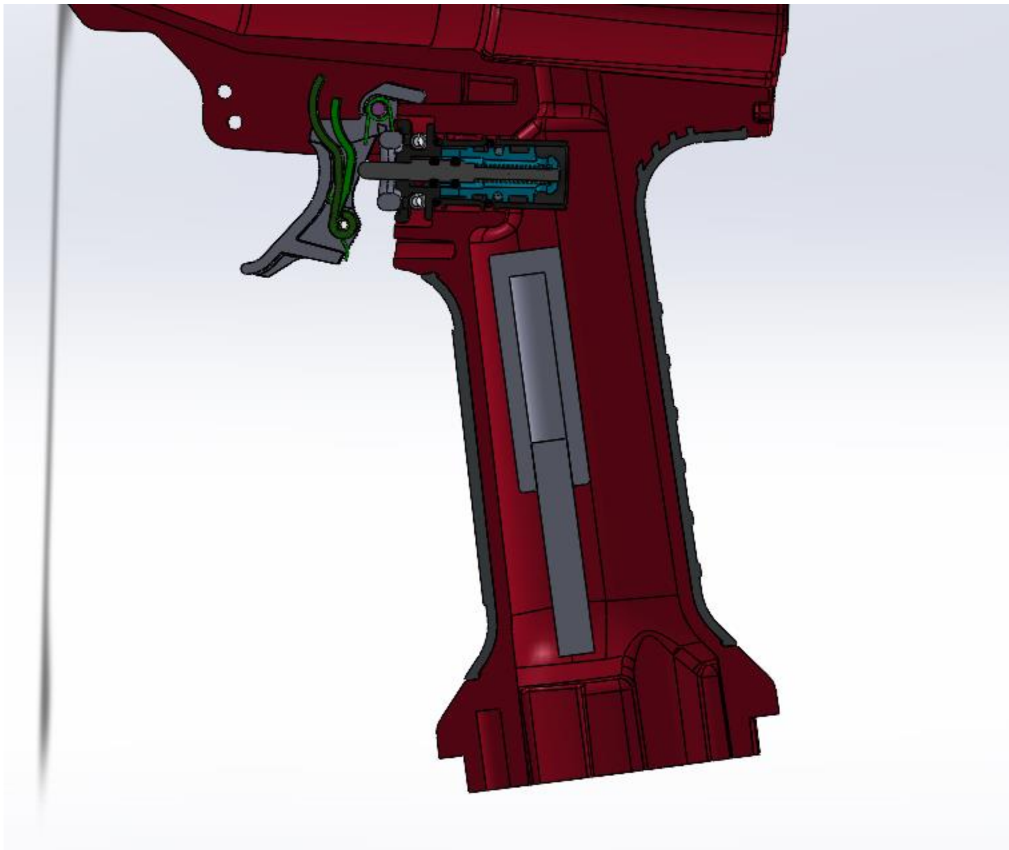
Because the new remote and trigger will maintain compatibility with current main body housings, the ergonomics and appearance should not change drastically.

Speed (14.8%)

Assuming all safety 'senses' have passed, the new trigger should allow the user to drive fasteners as fast as a standard tool that does not have the new trigger design. This is so that the end user is not impeded by the new design.

Design Analysis

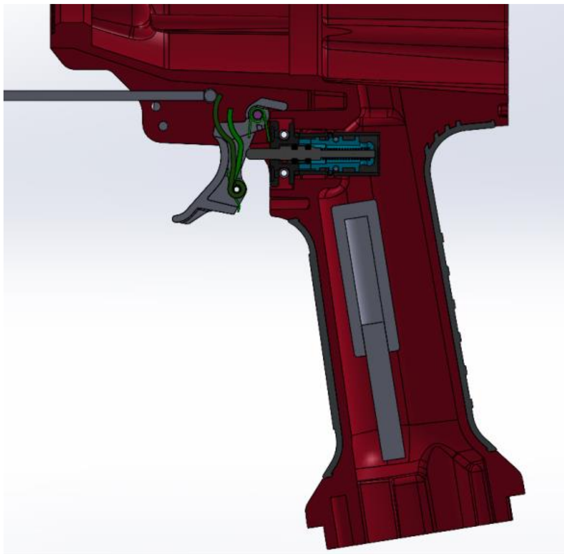
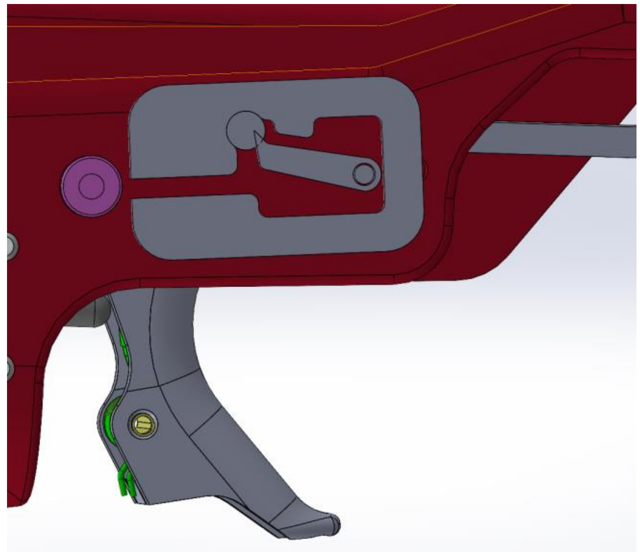
Initial Concept Drawings



Concept 1:

An inflatable ring that is slowly pumped up with air as the time delay ‘counts’ to three seconds. As this count is going on, a bleed valve system allows in a small amount of air from inside the tool to the chamber of the bleed system. Once the system ‘counts’ to three seconds the ring will be fully inflated requiring the trigger to be reset to the non-actuated position. Resetting the trigger to its origin will open a valve to bleed the inflated ring, allowing for the trigger to be depressed again. The setup will then continue as previously stated when the trigger is pulled.

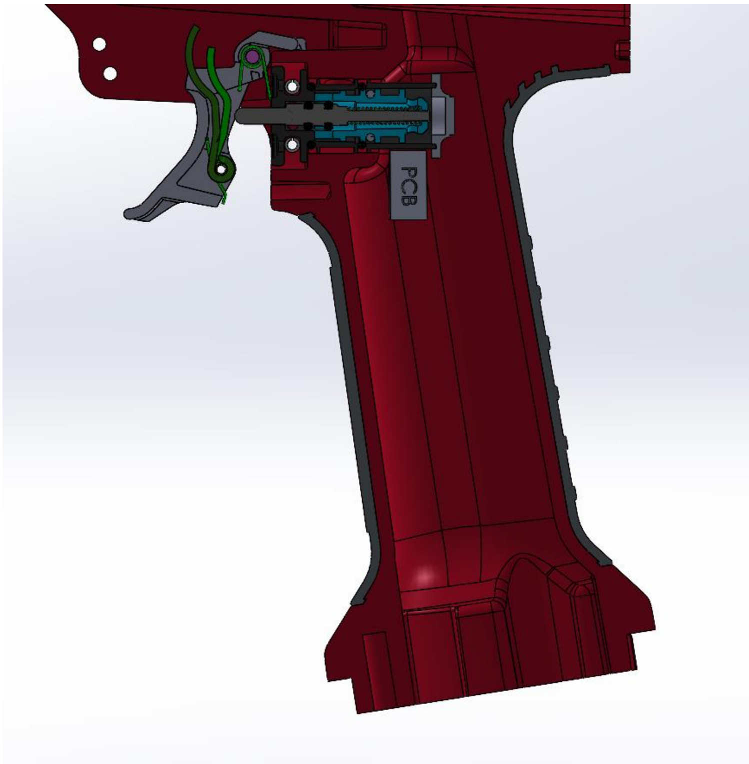
*For simplicity’s sake, not pictured in the concept is the inclusion of the valves/tubing connecting the main air intake to the ring, and the reset valving connecting the ring to the trigger.

Concept 2:

When the trigger is depressed, there is a valve system that allows air to enter an internal airline that will begin to build pressure in the path. Once the three second delay has been exceeded there is a spring-loaded pin that a lever hold that will be released and forced into the way of the safety member (Nose safety) locking the tool from firing. Once this occurs the user must release the trigger before the system will reset. When the trigger is released, the air built up will exit from an additional valve system mounted externally allowing the pin to be sprung back up and caught by the lever. Once this is complete the process can be repeated as the tool is unlocked again.

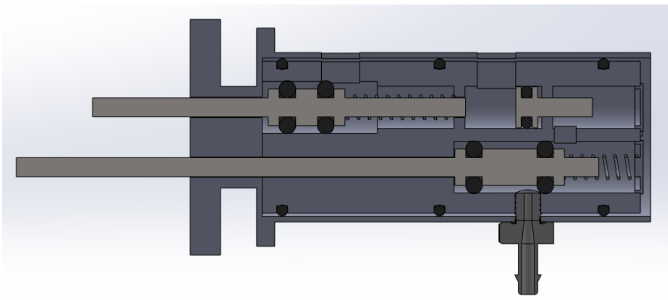
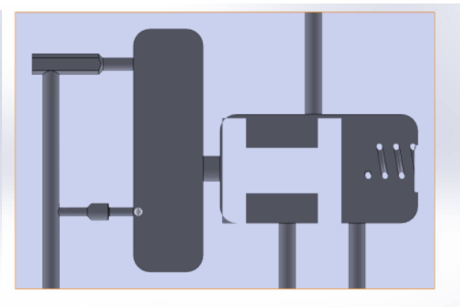
*Hidden in the image is the airline and the spring on the pin.



Concept 3:

There are two buttons and a sensor that are controlled through an internal PCB board. This board can be powered through an external or internal battery pack. The first button is activated when the user depresses the trigger allowing the button to be activated. This sends a single to the PCB board and begins an internal three second timer. Once the timer has been exceeded there is an electrically operated plug that is pushed into place blocking the remote stem from depressing. This locks the tool, and the user must release the trigger before using the tool again. This concept has a simpler idea behind it, like the ThinkTrac and modern Fusion tools. The downside of this concept is that it turns a pneumatic tool into an electric one that requires additional maintenance. This means that the customer who wants a pneumatic tool effectively receives a hybrid between pneumatic and electric.

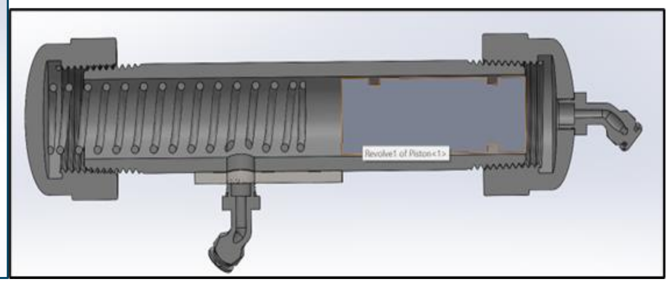
*Hidden from the image are electrical connectors.

Final Internal Design:

A modified remote assembly has been created in conjunction with a pneumatic time delay assembly. The new remote contains separate stems for the trigger and remote. The pneumatic timer is located inside the handle and begins to fill with air when the trigger stem is depressed. Once the delay begins bleeding air into the system, a plunger will compress a spring. The air path will allow the tool to fire within three seconds of the user depressing the trigger stem, but after three seconds, the plunger will block the remote stem from moving, stopping the tool from functioning. Once the trigger is released, the plunger is forced back, allowing the trigger stem to reset to the original state. This also allows air into the body of the tool.

While this design was promising in terms of functionality and would have provided the easiest transition while bringing the product to market, long lead times and inflated production costs prevented a sufficient prototype from being manufactured from suitable materials. The lead time of having a prototype injection molded with fiberglass reinforced nylon was too long to have adequate time to test because of the time needed to make the molds and ship the parts from overseas. The lead time to have a prototype injection molded domestically was also long and would have been prohibitively expensive to pursue when factoring in addition research and development parts.



External Design, Iteration 1:

Due to the difficulty of manufacturing an internal design, it was decided that an easily manufactured external prototype that used the same concepts as the internal design was the best course of action.

This concept was built out of easily procured parts from McMaster-Carr with a high focus on lead times due to excess time being spent on the internal design. The design features an in house designed air fitting for the tool with a 4mm OD quick disconnect fitting. This allows the tool to receive the needed air to operate and allow a small amount of that or to be routed to the two way valve. This valve is linked to the tools trigger as that when the trigger is depressed the mechanical lever is also depressed. This allows the air to flow from the two way valve into a time delay. This time delay was constructed out of schedule 80 steel, a piston created from a piece of 1045 steel, several O-rings, quick disconnect air fittings, and a spring. The delay functioned as air would come through the delay the piston would move compressing the spring to a point where the piston is no longer sealing another air fitting allowing the air to be routed to the top cap sealing the tool.

Selected Design

While the external design will not be the final design iteration that will be brought to market, it fulfilled the requirement of providing a prototype to act as a proof of concept for using a two way valve in concert with a pneumatic timer to provide an ISO compliant time delay system.

The selected design is different from the previously selected internal design. This design differs as it is an external system which adds additional bulk but is the most simplistic, reliable, and easily sourced. The design features an in house designed air fitting for the tool with a 4mm OD quick disconnect fitting. This allows the tool to receive the needed air to operate and allow a small amount of that or to be routed to the two way valve. This valve is linked to the tools trigger as that when the trigger is depressed the mechanical lever is also depressed. This allows the air to flow from the two way valve into the Festo time delay. This time delay is built to function from 0.1MPa to 1MPa and a time delay of between 1 and 5 seconds. For the system we have the delay is set to 3 seconds and operates once the two way valve allows air to flow into the delay. Once that 3 seconds delay is surpassed the air is routed into the top cap of the tool which creates a pressure pocket not allowing the tool to 'pre-vent' and locking the tool. When the delay is not surpassed the tool can 'pre-vent' and can fire under normal operations.

Loading Conditions

The tool must be able to function from 0.48 MPa up to 0.83 MPa

- The tool must survive 2 minutes at 1.38 MPa without actuating
- The tool must survive 2 minutes at 4.14 MPa without rupturing

The tool must be able to function within -5°C to 50°C

- The tool must survive at 82°C

The Kinetic Energy of the tool was calculated to be 7.277 x 10^4 N*m

- KE = Displacement * Input Pressure * Storage Volume
- KE = (84.7 mm * 0.828 N/mm^2 * 1,038,027 mm^3) / 1000mm

Factors of Safety and Applicable Regulations

The upcoming regulation mentioned in the problem statement, ISO 11148-13:2022, is the primary driver of this new design. This regulation will now require newly produced pneumatic fastener driving tools to include a time-out feature, where if the trigger is held down for a predetermined amount of time without a fastener being driven, the tool will be deactivated, so even if the safety member is depressed, the tool will not fire a fastener. The timeout feature will be reset by releasing the trigger.

The safety factors are laid out in ANSI SNT-101-2015, which includes regulations for pneumatically powered fastener drivers. There are two applicable sections, one sets a factor of safety for the pressure bearing main body, and the second one sets a factor of safety for the internal parts.

The first section stipulates that the main body must withstand 5x the tool's maximum stated pressure without rupturing. For these tests, the tool is stripped down so that only the tool main body remains. The main body is plugged and pressurized to 5x the maximum stated pressure, 4.14 MPa to guarantee that the tool can withstand high pressure.

The second test utilized a fully assembled tool, where the fully assembled tool is pressurized to 1.5x the tool's maximum stated pressure or 1.38 MPa, whichever is higher. The tool is then kept at that pressure for two minutes, where it must not self-actuate to pass the test.

Component and Material Selection

The internal design was meant to be prototyped out of 3D printed resin. This was meant for ease of manufacturing and speed of design changes. The prints would be printed in house, with the final design being made out of glass filled nylon. In addition to that, the final design would have been made through injection molding to increase production quantity and quality versus 3D printing. The remote stem prototypes would have been machined from low carbon steel, while the final, production versions would have been cast.

When designing the external time delay system, the component selection was driven by parts availability and lead times, due to the additional time constraints from having to change designs. Valves and fittings were selected based on lead times and meeting minimum pressure ratings, while the time delay valve was designed to be made from readily available components and hardware that was stocked at SENCO. Schedule 80 steel pipe and thick wall end caps were chosen to prototype the time delay system's pneumatic cylinder due to the low cost and high strength. Using steel pipe instead of a commercial single-acting pneumatic cylinder allowed for easier modifications, as an exhaust port had to be added to the wall of the cylinder and a manufactured cylinder did not provide enough wall thickness to do so. Manufacturing a pneumatic cylinder also provided more freedom for modification and revision, like changing the spring force, as most of the single acting cylinders available from industrial suppliers were not meant to be rebuildable or able to be disassembled or reassembled. 6061 aluminum was chosen for the piston material because it provided sufficient strength, while being easy to machine with available tools. Nitrile O-rings were chosen because the wide availability and standardization of sizes simplified calculations.

The final prototype used mostly the same component types as the previous external design, but with a commercial pneumatic time delay valve and a higher quality two way valve. The SMC two way valve was chosen after proving the functionality with the cheaper, more quickly available valve, for its higher quality and more consistent operation, which allowed for better performance during testing. The Festo pneumatic timer was chosen for its use among a variety of pressures allowing the time delay to be utilized by every Senco tool that is pneumatic.

Fabrication, Testing, and Assembly

The prototype for the internal design was manufactured primarily using resin 3D printing. Resin printing was chosen due to its dimensional accuracy and mechanical properties. Although the 3D printed prototype performed well with the test fit with finishing operations, the resin used and available at SENCO did not offer the mechanical properties or precision to seal the remote stems at operating pressure. Although the final product's remote housings would have been made from injection molded, fiberglass reinforced nylon, manufacturing a prototype from this material was not feasible, as the provided lead times from overseas injection molding companies would not have allowed for adequate testing before the end of the term, and domestic injection molding plants were prohibitively expensive, as the internal design's remote system required multiple molds to be made. The cost would have only increased, if the design required revisions and further development, requiring more molds and more parts to be manufactured. While this would have worked for a large production run, it was not feasible to create a prototype with the given budget and time constraints.

The external design was manufactured in two phases; the first iteration used a commercial two way valve and an in-house designed and manufactured time delay system to test the concept while searching for and awaiting delivery of the commercial model, while the second and final iteration utilized a commercial time delay valve. The prototype for the external design was manufactured primarily using off the shelf components, and with readily available materials for the custom designed time delay valve. The two way valve and fittings were sourced from Amazon to expedite the testing process, while more niche hardware was sourced from common industrial supply vendors. To manufacture the time delay system, the end cap was drilled and tapped to accept a threaded hose fitting, and extra material was welded to the wall of the pipe to allow for a threaded hose fitting to be threaded into the wall with full thread engagement. The piston was machined from 6061 aluminum bar stock, with O-ring grooves cut and the outer diameter turned down to provide the necessary seal between the piston and cylinder wall. Due to the relative simplicity of the necessary parts, ongoing projects at SENCO and limited available resources at the 1819 Innovation Hub, the parts were machined and fabricated at the Victory Parkway Campus machine shop and at a home machine shop. After machining and initial function testing, mounting brackets for the added hardware were 3D printed using conventional PLA filament. All parts were assembled by hand with common tools.

Testing Methods

Following initial function testing, the prototype was subject to SENCO Cycle Box Testing and SENCO Drive Testing. SENCO Cycle Box Testing utilizes an automated system to fire the tool rapidly and constantly to determine the longevity of the tool under ideal conditions to determine part wear over extended periods of time. SENCO Drive Testing is performed by a technician who fires the tool repeatedly, while simulating real world conditions. While Cycle Box Testing can determine long-term reliability of the tool, Drive Testing determines weak points under realistic conditions, while giving input to the ergonomic features of the tool.

The structural integrity of the tool was tested according to ANSI SNT-101-2015 on existing SENCO equipment. To test the structural integrity of the pressure bearing vessel, the part was put into a sealed container and pressurized to 5x the maximum operating pressure, 4.14 MPa, to ensure that the main body would not rupture. The second test for ANSI compliance was performed on the same test fixture and where the fully assembled tool with the time delay system was pressurized to 1.38 MPa for two minutes to ensure that the tool would not fire when subjected to overpressure. Because modifications to the pressure vessel were minimal, the 4.14 MPa pressure proof was of minimal concern, and because the prototype was not the final product to be brought to market, the 1.38 MPa was less relevant than for the system that will be brought to market.

As the ISO regulation has not been finalized, there is a lot to still be detailed in the standard. With this, the time delay testing protocols have not been detailed in the regulation yet. That said the current testing protocol has been to verify functionality of the delay while drive testing the tool. This will verify the functionality of the delay throughout the lifespan of the tool. Future regulation may detail the removal of the time delay from the system, as it would be equivalent to removing a safety, but for the scope of our project the tool will make a heavily audible air leak allowing the operator to hear this.

Testing Results

To test the newly designed time delay tool, drive testing was the most ideal way to understand the functionality. During a drive test each component can be evaluated to determine the lifespan and how much wear each part will receive. During the several hours where the modified tool was tested, 3,000 fasteners were fired through the tool with the time delay being tested on every strip of fasteners (~50 fasteners). By the end of the testing the newly added components were still functioning as expected. When the testing continues for a longer duration, more information can be learned about the prototype and when the production design is being created the finding from this prototype can be utilized to create a more durable end product.

Proof of Design

The components used were the following:

- Festo: VZO-3-PK-3
    - Operating Pressure: 0.25-1 MPa
    - Max Pressure: 1.25 MPa, industry minimum F.O.S)
- SMC: VM1000
    - Operating Pressure: 0.25-1 MPa
    - Max Pressure: 1.25 MPa, industry minimum F.O.S
- McMaster-Carr Air Hose
    - Max Pressure: 1.45 MPa

Project Management

Proposed Schedule:

Senior Design I: August 22, 2022 - Creation of senior design project, Formalized report of approved product

Senior Design II: October 11, 2022 - Completion of design parameters, Constructed 3D model of proposed solution

Presentation I: December 5 - December 8, 2022

Senior Design III: January 9, 2023 - Manufacturing and prototyping of concept, Final finished product ready

Tech Expo: April 6, 2023

Final Presentation: April 26, 2023

Progress to Date:

October 30, 2022 - Continued patent research, Began calculations

November 6, 2022 - Calculated factor of safety and received specifications and standards

November 13, 2022 - Calculated KE needs based on current tool design, Received Solidworks models and began analysis and measurement

November 20, 2022 - Completed Solidworks analysis and measurements

November 27, 2022 - Chose design concept and began finalizing details

December 07, 2022 - Continued sourcing design parts and began CAD designs.

January 29, 2023 - Revised CAD models and drawings for internal design, adjusted part fitment and manufacturability. Added to SENCO 3D printing queue.

February 05, 2023 - 3D printed first internal remote system, noticed design weaknesses that would affect functionality. Revised internal design. Began conceptualizing external design. [Week 4]

February 12, 2023 - Revised 3D print prototype printed. [Week 5]

February 19, 2023 - Officially abandoned internal concept and began designing external system. [Week 6]

February 26, 2023 - Completed CAD design of external design. Began sourcing parts and hardware. [Week 7]

March 5, 2023 - Placed purchase order for parts and hardware, began machining piston. [Week 8]

March 12, 2023 - Parts received, began test fitting and attempted assembly. Second PO submitted for additional parts and materials. [Week 9]

March 26, 2023 - External time delay valve manufactured, began revising dimensions and tolerances to resolve issues with part fitment. Ordered additional necessary parts. [Week 10]

April 02, 2023 - Prepared for and submitted video for Tech Expo. Began modifying and remanufacturing time delay valve. Researched commercial options for time delay valve systems. [Week 11]

April 14, 2023 - Newest revision designed and began modifying tools to install components. [Week 12]

April 24, 2023 - The design was installed onto a tool and began to drive cycling to test lifespan. [Week 13]

Project Budget Limit

Proposed Budget: $5,000

Material	Specifications	Amount	Projected Cost	Actual Cost
Thick Wall Steel Seamless Pipe	6” Threaded	2	$30	$27.30
Iron Pipe Fitting Cap	Medium Pressure, 1 NPT	4	$90	$88.52
High-Strength 1045 Carbon Steel Rod	1” Dia x 1’ Length	1	$15	$11.18
6061 Aluminum Rod	1” Dia x 3’ Length	1	$25	$25.76
Hard Nylon Plastic Tubing	2.7mm ID, 4mm OD, 25’ Length	1	$10	$9.00
Push-to-Connect Tube Fittings, 45°	4mm Tube OD x ⅛” Pipe Size	2	$5	$5.06
302 Stainless Steel Comp. Spring	4” Long, 0/938” OD, 0.642” ID	3	$20	$16.81
Buna-N O-Rings	⅛” Width, -210	(100)	$10	$10.04
Buna-N O-Rings, Soft	⅛” Width, -210	(50)	$10	$11.62
SMC - 2 Way Mechanical Valve	VM1000	1	$100	$110.75
Festo - Time Delay	VZO	1	$400	$410.69
3D Printing	FDM & Resin	12 Hours	$20	$25
Machining	$50/Hour	15 Hours	$750	$0
Total			**$ 1,485**	**$ 766.10**

Conclusion and Recommendation

The final external design met the original goal of providing a design and prototype for a fully pneumatic, ISO 11148-13 compliant time delay system. Although having a design that could be immediately integrated into current product lines would have been ideal, time and budgetary constraints made providing an internal design unfeasible, thus an external system that did not alter the pressure-bearing main body was designed. This external design functions as designed and applies the same concepts as the final iteration of the internal design, but was significantly quicker and cheaper to produce for a prototype.

Future design iterations will most likely involve expanding on and refining an internal design concept to bring to market. While the final internal design appeared promising, the timeline and cost to manufacture a prototype was outside the constraints of this project. With a larger budget and further deadline to manufacture a prototype from suitable materials and test it, the internal design likely would have yielded a workable design with further research and development.

References

1. EIBEN, Frank J, HALBERT, Eric H, JOBE, William T and SIEGMANN, Carl. United States Patent 3,964,659. *Safety firing control means for a fluid operated tool* [online]. 12 March 1975. [Accessed 8 September 2022]. Available from: https://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&d=PALL&p=1&u=%2Fnetahtml%2FPTO%2Fsrchnum.htm&r=1&f=G&l=50&s1=3964659.PN.&OS=PN/3964659&RS=PN/3964659
2. ISO 11148-13:2017. *ISO* [online]. November 2017. [Accessed 8 September 2022]. Available from: https://www.iso.org/standard/50142.html#:~:text=ISO%2011148-13%3A2017%20is%20applicable%20to%20fastener%20driving%20tools,the%20purpose%20of%20driving%20this%20into%20a%20workpiece
3. JOACHIM, Bauer. Compressed air nail gun with a manually actuated trigger and a contact sensor. *EP2767365A1* [online]. 20 August 2014. [Accessed 8 September 2022]. Available from: https://worldwide.espacenet.com/patent/search/family/047754280/publication/EP2767365A1?q=num+%3D+%22EP2767365%22&queryLang=en
4. KRAMER, Francis J. Electronic control for a pneumatic fastener driving tool. *United States Patent 4,679,719* [online]. 14 July 1987. [Accessed 8 September 2022]. Available from: https://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&d=PALL&p=1&u=%2Fnetahtml%2FPTO%2Fsrchnum.htm&r=1&f=G&l=50&s1=4679719.PN.&OS=PN/4679719&RS=PN/4679719
5. LAI, Chun-chi. Firing control device for a pneumatic tool. *United States Patent 10,335,936* [online]. 7 February 2019. [Accessed 8 September 2022]. Available from: https://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&d=PALL&p=1&u=%2Fnetahtml%2FPTO%2Fsrchnum.htm&r=1&f=G&l=50&s1=10,335,936.PN.&OS=PN/10,335,936&RS=PN/10,335,936
6. LAI, Chun-Chi. FIRING CONTROL DEVICE FOR A PNEUMATIC TOOL. *EP3263284A2* [online]. 1 March 2018. [Accessed 8 September 2022]. Available from: https://worldwide.espacenet.com/patent/search/family/058387668/publication/EP3263284A2?q=num+%3D+%22EP3263284%22&queryLang=en
7. MOORE, Stephen P, WEINGER, Murray Z, BIRK, Daniel J, ZHAO, Hanxin, SEGURA, Ricardo and FRANCIS, Ryan L. Fastener-driving tool including a reversion trigger. *United States Patent 10,213,911* [online]. 26 February 2019. [Accessed 8 September 2022]. Available from: https://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&d=PALL&p=1&u=%2Fnetahtml%2FPTO%2Fsrchnum.htm&r=1&f=G&l=50&s1=10,213,911.PN.&OS=PN/10,213,911&RS=PN/10,213,911
8. MOORMAN, Charles J. Pneumatic fastener driving tool and an electric control system, therefore. *United States Patent 6,382,492* [online]. 7 May 2002. [Accessed 8 September 2022]. Available from: https://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&d=PALL&p=1&u=%2Fnetahtml%2FPTO%2Fsrchnum.htm&r=1&f=G&l=50&s1=6,382,492.PN.&OS=PN/6,382,492&RS=PN/6,382,492
9. MOORMAN, Charles J. Pneumatic fastener driving tool and an electronic control system, therefore. *United States Patent 5,732,870* [online]. 31 March 1998. [Accessed 8 September 2022]. Available from: https://patft.uspto.gov/netacgi/nph-

Parser?Sect1=PTO1&Sect2=HITOFF&d=PALL&p=1&u=%2Fnetahtml%2FPTO%2Fsrchnum.htm&r=1&f=G&l=50&s1=5732870.PN.&OS=PN/5732870&RS=PN/5732870
10. MOORMAN, Charles J. Pneumatic fastener driving tool and an electronic control system, therefore. *United States Patent 5,918,788* [online]. 6 July 1999. [Accessed 8 September 2022]. Available from: https://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&d=PALL&p=1&u=%2Fnetahtml%2FPTO%2Fsrchnum.htm&r=1&f=G&l=50&s1=5,918,788.PN.&OS=PN/5,918,788&RS=PN/5,918,788
11. MOORMAN, Charles J. Pneumatic fastener driving tool and an electronic control system, therefore. *United States Patent 6,431,425* [online]. 13 August 2002. [Accessed 8 September 2022]. Available from: https://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&d=PALL&p=1&u=%2Fnetahtml%2FPTO%2Fsrchnum.htm&r=1&f=G&l=50&s1=6,431,425.PN.&OS=PN/6,431,425&RS=PN/6,431,425
12. PUPPALA, Madhav Sai and MOORE, Stephen. Fastener-driving tool including a reversion trigger with a damper. *United States Patent 9,662,776* [online]. 30 May 2017. [Accessed 8 September 2022]. Available from: https://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&d=PALL&p=1&u=%2Fnetahtml%2FPTO%2Fsrchnum.htm&r=1&f=G&l=50&s1=9,662,776.PN.&OS=PN/9,662,776&RS=PN/9,662,776
13. PUPPALA, Madhav Sai and MOORE, Stephen. Fastener-driving tool including a reversion trigger with a damper. *United States Patent 10,532,453* [online]. 14 January 2020. [Accessed 8 September 2022]. Available from: https://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&d=PALL&p=1&u=%2Fnetahtml%2FPTO%2Fsrchnum.htm&r=1&f=G&l=50&s1=10,532,453.PN.&OS=PN/10,532,453&RS=PN/10,532,453
14. SIEGMANN, Carl. Firing safety for a pneumatic nailer. *United States Patent 4,194,664* [online]. 25 March 1980. [Accessed 8 September 2022]. Available from: https://patft.uspto.gov/netacgi/nph-Parser?Sect1=PTO1&Sect2=HITOFF&d=PALL&p=1&u=%2Fnetahtml%2FPTO%2Fsrchnum.htm&r=1&f=G&l=50&s1=4,194,664.PN.&OS=PN/4,194,664&RS=PN/4,194,664
15. ROGERS, Murray H. Safety mechanism for pneumatic fastener driving machines. *United States Patent 3056965A* [online]. 9 October 1962. [Accessed 10 September 2022]. Available from: https://patents.google.com/patent/US3056965A/en?oq=US3056965A
16. BECHT, Carl T and RACER, James H. Firing control means. *United States Patent 3278106A.* [online]. 11 October 1966. [Accessed 10 September 2022]. Available from: https://patents.google.com/patent/US3278106A/en?oq=US3278106A
17. CHEN, Jacob. Single-shooting/continuous-shooting control switch for penumatic nail guns. *United States Patent 5522532A.* [online]. 4 June 1996. [Accessed 12 September 2022]. Available from: https://patents.google.com/patent/US5522532A/en?oq=US5522532A
18. MOORE, Stephen P, WEINGER, Murray Z, BIRK, Daniel J, ZHAO, Hanxin, SEGURA, Ricardo and FRANCIS, Ryan L. Fastener-driving tool including a reversion trigger. *United States Patent 20170129084A1*. [online]. 26 February 2019. [Accessed 15 September 2022]. Available from: https://patents.google.com/patent/US20170129084
19. PUPPALA, Madhav S and MOORE, Stephen. Fastener-driving tool including a reversion trigger with a damper. *United States Patent 9662776B2*. [online]. 30 May 2017. [Accessed 15 September 2022]. Available from: https://patents.google.com/patent/US9662776B2/en?oq=US9662776B2

20. What is the function of time delay valve? In *Time delay valve function explaination* [interaktyvus]. [žiūrėta 2022-12-05]. Prieiga per internetą: <https://mechdiploma.com/what-function-time-delay-valve>
21. Kazuya Mochizuki, Kousuke MORIWAKI, Hiroshi Tanaka. *Pneumatic tool. US 20210402577A1*, June 30, 2021. Design (Pending). Available from:
22. Kazuya Mochizuki, Kousuke MORIWAKI, Hiroshi Tanaka. *Pneumatic tool. US 20210402577A1*, June 30, 2021. Design (Pending). Available from: https://patents.google.com/patent/US20210402577A1/en?oq=20%2c210%2c402%2c577
23. What is the function of time delay valve? In *Time delay valve function explaination* [interaktyvus]. [žiūrėta 2022-12-05]. Prieiga per internetą: <https://mechdiploma.com/what-function-time-delay-valve>
24. INTERNATIONAL STAPLE, NAIL AND TOOL ASSOCIATION (ISANTA) International Staple, nail, and Tool Association. In *ANSI SNT-101-2015* [interaktyvus]. 2015. [žiūrėta 2022-12-08]. Prieiga per internetą: http://isanta.org/Portals/0/PDFs/ANSI%20SNT-101-2015.pdf?ver=2015-12-30-161900-753