Design of an Automatic Machine for Stripping and Bending Insulated Electrical Wire

by

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NOMENCLATURE

\( \omega \)  Angular Velocity (rad/sec)

\( f \)  Frequency (rpm)

\( \alpha \)  Angular Acceleration (rad/sec\(^2\))

\( T \)  Torque (ft-lbs)

\( I \)  Rotational Inertia (lb-ft\(^2\))

\( \mu \)  Coefficient of Friction (dimensionless)

\( r \)  Radius (in)

\( F \)  Force (lb)
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**ABSTRACT**

The aim of this project is to produce the mechanical design of an automatic machine for manufacturing segments of heavy gauge insulated electrical wire with both ends stripped and bent at 90 degrees from a spool stock of insulated electrical wire. These wire segments would be used in the assembly of electrical components such as battery banks, prefabricated circuit breaker panels, and other components where jumper/bridge segments are required. The design of the automatic wire stripping and bending machine will utilize seven subsystems which together compose the machine. Design of the machine is performed using Computer Aided Design (CAD) software to produce a 3D model of the machine. Each subsystem is shown and key design features are discussed with supporting rational for their implementation. Supporting calculations are performed to size various components used in each subsystem and load bearing areas throughout the machine are evaluated for stress. A timing diagram and input/output (I/O) listing is developed and a programmable logic controller (PLC) model selected to define the control system. The 3D CAD model allows a potential customer or colleague to produce 2D drawings for manufacture and assembly of the automatic machine.
1. Introduction

1.1 Background

1.1.1 Automation

Automation of a manufacturing process plays a vital role in reducing a company's production costs. The primary reasons for automating a manufacturing process are reducing labor costs, reducing waste, improving quality, increasing repeatability, reducing employee injuries, and allowing uninterrupted production.

1.1.2 Machine Function

The function of the automatic wire stripping and bending machine presented in this report is to produce segments of insulated electrical wire with both ends stripped from a spool of insulated wire. These segments are cut to lengths varying from 5 to 24 inches, and the stripped ends bent 90 degrees. The production rate of this machine is anticipated to produce a finished segment of wire every five seconds. Figure 1 shows the general layout of the seven subsystems, which together compose the machine. The automation of this process serves to replace the manual human operations previously used to produce a segment of wire as described above.
1.2 Problem Description

1.2.1 Requirements and Specifications

The requirements and specifications for the automatic wire stripping and bending machine are as follows:

- Produce wire segments with lengths ranging from 5 inches to 24 inches.
- Remove up to 1 inch of insulation from both ends of the wire segment.
- Bend both stripped ends of the wire segment 90 degrees in the same direction.
- Uncoil insulated wire automatically from spool stock.
- Produce a finished wire segment every 5 seconds.
- Control the automatic machine through a Programmable Logic Controller (PLC).
- Pneumatics of the machine to use 90 psi shop air supply.
- Simple manual adjustment for different segment length production runs.
- Hands free operation once setup and programmed for specific segment length.
- Sensor feedback to stop machine and notify operator when jam or malfunction occurs.
- Machine to be located on bench top when in use.
2. Machine Design

2.1 Subsystem #1: Free-Length Uncoiling Mechanism

2.1.1 System Description

Subsystem #1, shown above in Figure 2, uncoils a free-length amount of wire from a spool stock of insulated wire. The mechanism consists of a drive roller (part number (PN) X) with an idle roller which is tensioned against the insulated wire by a spring (PN X). The drive roller is rotated by and DC electric motor (PN 1). The free-length is regulated by two inductive proximity switches.

The two proximity switches are used to provide feedback to the mechanism which uncoils wire from the spool stock. The proximity switches are located at a set distance vertically apart from each other to provide a free length of wire 72 inches in length. As the lower sensor detects the wire it will cause the uncoiling mechanism to stop. Once the free length of wire is consumed by the machine the free length of wire is shortened to the point where the upper proximity sensor detects the wire and provides a signal to turn
the uncoiling mechanism on until the wire droops into the detecting space of the lower sensor.

2.1.2 Analytical Support

2.1.2.1 Electric Motor

The design of Subsystem #1 is based on uncoiling a 20 inch diameter spool of #12 single-conductor insulated copper wire weighing 62.5 lbs. Subsystem #1 is designed to uncoil a free-length of wire 72 inches long in 2 seconds. To achieve this requirement, a 20 inch diameter spool must rotate at 35 rpm. For conservatism, a 1 second time to reach 35 rpm is assumed when calculating the required torque. The torque required to rotate the spool is given by the following, where 308 is a combined constant converting minutes into seconds, weight into mass and radius into circumference:

\[
T = \frac{N \times WR^2}{t \times 308} = \frac{35 \text{rpm} \times 21.7 \text{lb-ft} - ft^2}{1 \text{sec} \times 308} = 2.47 \text{ ft-lb}
\]  

(1)

The pull force required to meet above torque requirement at the outer perimeter of the spool is calculated:

\[
F = \frac{T}{r} = \frac{2.47 \text{ ft-lb}}{10 \text{ in}} = 2.97 \text{ lb}
\]

(2)

The above pull force is used to calculate the required minimum torque for the motor (PN X in Figure 2) coupled to the 1.7 inch diameter drive pulley (PN X in Figure 2):

\[
T_m = F \times r = 2.97 \text{ lb} \times 0.85 \text{ in} = 2.52 \text{ in-lb}
\]

(3)

From the results of equations (1) through (3), a NEMA 34 frame electric stepper motor, as selected in the design, provides sufficient margin for required torque to uncoil 72 inches of wire in 2 seconds. NEMA 34 stepper motors typically range in maximum
torque ratings from 18in-lb to 75in-lb. In addition, the margin for required torque would allow the spool size to be increased in size and weight.

2.1.2.2 Extension Spring

Based on an assumed coefficient of friction of 0.25 for aluminum with nylon, the clamping force required between the drive pulleys is as follows:

\[
F_n = \frac{F}{\mu} = \frac{2.97lb}{0.25} = 11.88lb
\]  

(4)

Based on the dimensions of the idle pulley arm (PN X in Figure 2), the required extension spring (PN X in Figure 2) is selected to provide a compressive load of 6lb.

2.1.2.3 Shafts

2.1.2.4 Bearings
2.2 Subsystem #2: Primary Feed Mechanism

2.2.1 System Description

The primary feed mechanism, shown in Figure 3, draws insulated wire from the free length of wire maintained by Subsystem #1. This wire is fed along through the guide tube of Subsystem #3. The rollers of this mechanism are driven by an electric stepper motor (PN X in Figure 3), timing pulleys (PN X in Figure 3), and timing belt (PN X in Figure 3). An idle roller attached to a tension block is used to tension to the timing belt and provide engagement across all three timing pulleys. The tension block functions by housing two compression springs guided by two shoulder bolts with bushings. The lower idle pulleys (PN X in Figure 3) are mounted to a floating housing which is tensioned.
against the drive pulleys in a similar fashion as the timing belt tension block described above. The lower idle pulleys provide a compressive load against the insulated wire and drive pulleys, thus preventing any slip in the drive mechanism.

The wire length is determined by the amount of rotations of the drive wheels to accurately measure out the length of wire to be cut by the cutting/stripping station (Subsystem #4). This subsystem also moves the wire in reverse to perform the stripping operation once the jaws of Subsystem #4 are clamped down in the strip position.
2.2.2 Analytical Support

2.3 Subsystem #3: Guide Tube

2.3.1 System Description

Figure 4: Guide Tube Mechanism

The funneled guide tube (PN X in Figure 4) guides the insulated wire to the stripping/cutting station and performs addition straightening of the wire. The funneled tube is interchangeable for different gauge wire and is mounted to a solenoid (PN X in Figure 4) actuated rotation assembly. The rotation of the guide tube allows for the leading end of the following wire to be moved out of the way when a segment of wire is back-fed into the stripping/cutting station for the second stripping operation.
2.3.2 Analytical Support

2.4 Subsystem #4: Cutting and Stripping Mechanism

2.4.1 System Description

Figure 5: Cutting / Stripping Mechanism

The cutting and stripping operations are performed by a set of dies which are actuated by a linear cam mechanism. This linear cam plate (PN X in Figure 5) is actuated by a pneumatic cylinder (PN 17), which produces a clamping motion via cam followers (PN X in Figure 5) on each of the clamp arms (PN X in Figure 5). The stripping/cutting die (PN X in Figure 5) is interchangeable for different gauge wires. The initial end of the wire is fed into the stripping station, the jaws contract over the wire with the dies. This stripping position is set by an intermediate stop which is engaged by a smaller
pneumatic cylinder (PN X in Figure 5). Once the insulation is cut, the feed mechanism from Subsystem #2 rotates in reverse to pull the insulation off the end of the wire.

The wire is then fed forward for a predetermined segment length and captured by the secondary feed mechanism (Subsystem #4). The wire is cut by allowing the pneumatic cylinder attached to the linear cam plate (PN X in Figure 5) to go through its entire stroke. In order to strip the second end of the wire segment, the guide tube of Subsystem #2 is rotated upwards, the feed mechanism of Subsystem #4 feeds the segment in reverse through the stripping jaws where the action described in the paragraph above is performed again.

2.4.2 Analytical Support
2.5 Subsystem #5: Secondary Feed Mechanisms

2.5.1 System Description

The secondary feed mechanism is identical to the one shown in Figure 3 except a sensor is incorporated into the right-most idle pulley. The sensor allows the machine to sense when the segment of wire has been completely transferred to the drop slide, shown in Figure 6.

Figure 6: Secondary Feed Mechanisms

The secondary feed mechanism is identical to the one shown in Figure 3 except a sensor is incorporated into the right-most idle pulley. The sensor allows the machine to sense when the segment of wire has been completely transferred to the drop slide, shown in Figure 6.
The sensor dictates when the drop slide opens and allows the stripped wire segment to fall onto the walking beam. For this sensor a magnetic reed switch is used. The stripped wire segment will travel over an idle roller when being transferred from the secondary feed mechanism to the drop tray. This idle roller will contain a magnet which the reed switch will be able to sense when the idle roller is rotating. This will allow the machine to determine when the wire segment has been completely transferred the secondary feed mechanism to the drop tray. Once the wire segment is in the drop tray (Figure 6), the tray can open and drop the wire segment onto the walking beam (Subsystem #6). The magnetic reed switch allows for the timing of opening the drop tray without the wire segment becoming jammed in the feed mechanism.

The drop slide mechanism consists of a hinged sheet metal plate (PN X in Figure 6) which can accommodate lengths of wire 5 inches through 24 inches without adjustment. The drop slide is opened by a pneumatic cylinder (PN X in Figure 6), allowing the wire to fall onto the first step of the stationary portion of the walking beam mechanism (Subsystem #5).

2.5.2 Analytical Support
2.6 Subsystem #6: Walking Beam

2.6.1 System Description

A walking beam mechanism, shown in Figure 7, is used to move the stripped wire segment from the path of cutting and stripping to the bending station. The bending station (Subsystem #7) is incorporated into the stationary portion of the walking beam and is discussed in paragraph 2.7.1.

The walking beam is actuated by rotating four offset hubs (two on each side) mounted in the stationary portion of the walking beam. The rotation of the hubs is driven by an electric motor and timing belts. Rotation from the electric motor to the rotating hub is transferred via a solenoid activated clutch (PN X in Figure 7). The motor operates constantly and when a wire segment is dropped from Subsystem #4, the clutch is engaged for one revolution of the walking beam. The walking beam is adjustable for lengths of wire 4 inches to 24 inches by turning an acme screw (PN X in Figure 7), which will move the second assembly along two liner slides (PN X in Figure 7). The
adjustable side of the walking beam is driven by a hex shaft (PN X in Figure 7) through hex bushings (PN X in Figure 7).

2.6.2 Analytical Support

2.7 Subsystem #7: Bending Mechanism

2.7.1 System Description

Figure 8: Bending Mechanism
The bending of both stripped ends is completed by actuating two dies vertically down with pneumatic cylinders (PN X of Figure 8). The dies are slightly offset from the edge of the walking beam stationary rail to account of the thickness of the un-insulated wire. A spring (PN X of Figure 8) loaded guide block is incorporated into the die to prevent the wire from moving during the bending operation. The die is mounted on a linear slide (PN X of Figure 8) to provide smooth, rigid motion. The gantry style setup is adjustable for the 5 inch to 24 inch wire lengths by moving the right side assembly on a linear slide (PN X of Figure 8), and locking it in place.

After the bending operation is complete, the part will be removed during the next cycle of the walking beam (Subsystem #5) and dropped on a slide where the wire segments can be collected in a bin.

2.7.2 Analytical Support
3. Full Machine

3.1 Machine Description

Figure 9: Full Machine

3.2 Control System