Cost-effective automatic winder machine for optical fiber filament

Devanadora automática de bajo costo y precisión para filamento de fibra óptica

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Abstract

In the market of equipements to wind optical fiber, there are winding machines, which are usually expensive and the ones that are not expensive, can present an important error at the moment to make large fiber rolls in the order of kilometers, these rolls cab be used for selling, storage or for instrumentation applications (in this case, using the optical fiber as sensor to measure some variables such as structure deformation, etc). That is way is necessary to have an equipment, that allow to wind large stretches of fiber at a low cost and effectivity. A propose of a small error winding is presented in this work, a good alternative is shown in this project by using a low-cost micro controller and semiconductors.

Optical fiber inovation, Instrumentation, automation, Winding machine alternative

Resumen

En el mercado de quipos para devanar fibra óptica, existen maquinas embobinadoras que suelen ser costosas y las que no son costosas pueden presentar un error considerable al momento de hacer rollos de fibra que sean de longitudes grandes en el orden de kilómetros, lo que puede llevar a un desperdicio de material cuando se realizan dichos rollos, ya sea para sus venta, almacenamiento o para aplicaciones de instrumentación (utilizando la fibra como un sensor para medir alguna variable, como deformación de estructuras, etc). Por lo que es necesario contar con un equipo que permite devanar tramos largos de fibra óptica a un bajo costo y con efectividad. Este trabajo, ofrece una propuesta de un sistema que presenta un bajo error a la hora de crear rollos de fibra y resulta una propuesta económica al utilizar un microcontrolador y semiconductores de bajo costo.

Innovación en fibra óptica, Instrumentación, Automatización, Alternativa de bobinado

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Introduction

For optical fiber filament winding, a winding machine is a necessary tool to make work easier. Several wire and optical fiber filament winding machines have become a topic of interest for many aspects such as tension control, wire aligning, system control and control by vision, among others. When the time for copper wire winding is needed, a control torque scheme is suitable depending on the wire gauge, as explained by Deng 2021. For thin wire diameters, tension control is required in order to keep turns identically wound, opposite to thick wires, where torque regulation is a must to ensure winding process continue running despite the stiffness of the wire. On the other hand, for optical fiber filament, high-speed and precision alignment control is mandatory to wind long lengths of filaments. In addition, some other works based their investigations on the economic impact using these systems to increase the amount of filament spool productions as reported Ferrer-Alos and Sanchez 2022.

Several optical fiber filament winding machines have been reported in literature, such as the systems described by Campos 2022, Ming 2011 and Ferrer-ALOS 2022, where fiber stress analysis is taken into consideration into their mathematical model and an error method is presented, respectively.

The importance of reducing the winding error lays on the fact that for long length of optical fiber filament multiply by the error, will lead us to a considerable material waste. In Kanade 2018, that fact is mentioned and a control algorithm is well described and implemented on a micro controller to ensure a proper material distribution.

Other works related to winding optical fiber include digital image processing, tensors methods, where the aligning angle is observed and computed by image recognition, this may lead to an expensive approach, as described by Mosquera 2022 and Kang 2020. Finally, it is important to mention some applications for optical fiber coil, such as sensor for sea floor seismic Monitoring (Chen et all, 2016), optical fiber gyroscope (Korkishko 2011) and

Fiber winding systems

Essentially, Optical fiber winding machines are conformed by a mechanic part to hold the spool and another part to align the filament along the spool, as it can be observed on figure 1.

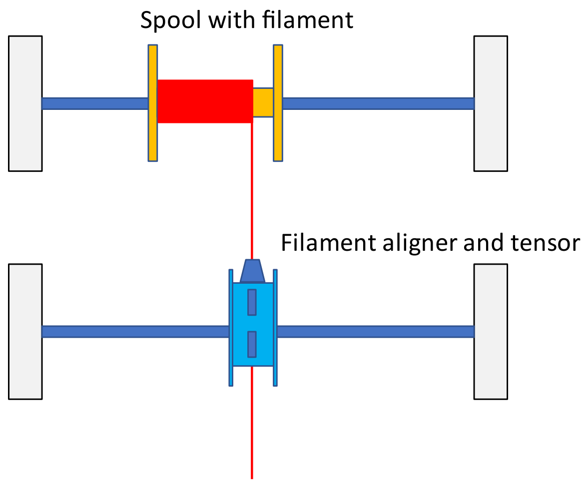

Figure 1 Basic winding machine scheme

The coil wounded upon the spool is formed by the movement of the aligner, which distributes the optical filament on the spool surface, while the tensor is necessary to keep a constant tension on the filament during the aligner displacement. Before this action takes place, system has to ensure the amount of optical fiber filament fits in the spool size, so the number of turns and layers must be calculated in advanced.

Each turn is measured by a motor-shaft-connected incremental encoder, once the number of turns is accomplished on each layer, the aligner starts going backward to make the next layer, and so on.

System operation

In the system functioning, there are some steps to follow. First, the spool inner and outer diameters and optical fiber filament must be set in its place and alighted by the interface using the keys on the keyboard, the alignment is control by the Time-Of-Flight (ToF) sensor and the aligning car. That car is moved by a stepper motor. Second, spool and filament must be introduced on the display interface, number of turns and layers must be calculated and compared to see if they fit in the spool, the result is then display so user can know if the spool is suitable for the amount of optical fiber filament and the spool.

This sequence is shown in the block diagram of the figure 2. If the optical fiber filament does not fit in the spool, the system interface sends an alert message to indicate to chance the spool size or the amount of filament to wind, after new parameters need to be introduced; finally, the system again has to calculate if the design is going to fit.

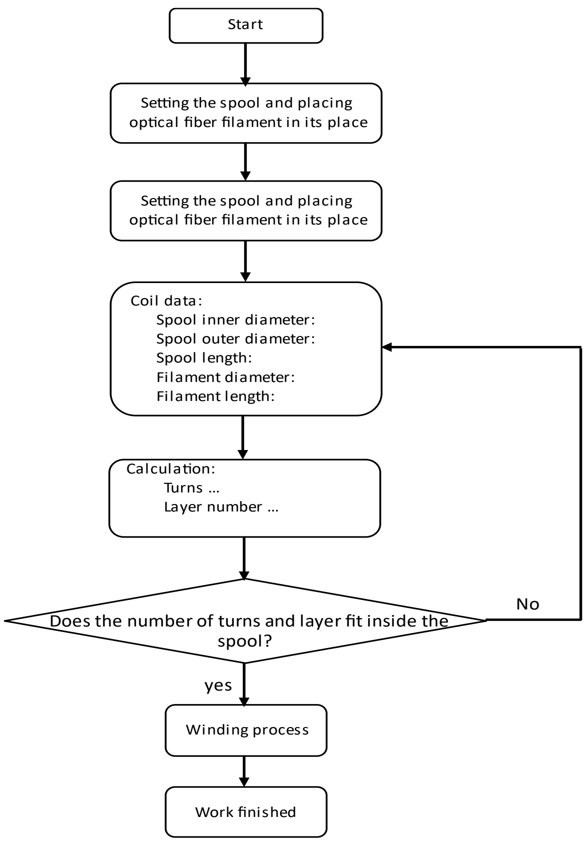

Figure 2 Block diagram for machine sequence operation

Base on this algorithm, the design is easier to understand and the procedure is friendly to follow and the user can performance a design.

Error estimation

In order to estimate the number of turns, layers and error, the following algorithm is implemented in the system board:

```
d1=0;% spool inner diameter (mm)
d2=0;% spool outer diameter (mm)
d3=0;% optical fiber filament diameter (mm)

L=0;% spool inner length (mm)
Lf1=0;% optical fiber filament length (m)
Lf2=0;% aux optical fiber filament length (m)

Nturns=0;% number of turns (#)
Rad1=0;% spool inner radio (mm)
```

```
% Proceso
d1=input('spool inner diameter (mm)=');
d2=input('spool outer diameter (mm)=');
d3=input(‘optical fiber filament diameter (mm)=');

L=input(‘spool inner length (mm)=');
Lf1=input('longitud de la fibra (m)=');
Lf2=Lf1*1000; % contertions from m to mm
Rad1=d1/2;
Nturns =fix((L/d3));% number of turns (#)

i=0;
Cont1=0;
Lacum=0;
Cond=1;
Turn=0;
while Cond==1
  Lacum=Lacum+(2*pi*(Rad1+(d3*i)));
  Cont1=Cont1+1;
  Turn=Turn+1;
  if Cont1== Nturns
     i=i+1;
     Cont1=0;
  end

  if Lacum>=Lf2
     Cond=0;
  else
     Cond=1;
  end
end
disp(Spool Thickness mm');
Res=d2-d1
disp('Layer Hight mm');
Alt=fix(d3*i)
if Res<Alt
   disp('Design does not fit');
else
   disp('Design fits')
end
disp('optical fiber filament length en mm');
disp(Lf2)
disp(‘acumulated optical fiber filament length en mm');
disp(Lacum);
disp('Number of layers');
disp(i);
disp('Number of turns per layer');
disp(Nturns);
disp(‘Total number of turns);
disp(Turn);

error=((Lacum-Lf2)/Lf2)*100;

disp(‘The % of error is=')
disp(error)
```

System proposed

The winding system is conformed by an ATmega2560 microcontroller embedded in a fast-development board with pin connectors, which simplifies its implementation. A ToF sensor (VL53L4CD) with a resolution of millimeters to detect where the spool is located on the horizontal axe, then to be able to set its point of start (home) for the aligner car in order to star winding the filament. To move the aligning car, a stepper motor is activated by a set of pulses sent by the system board, as mentioned before, the stepper is a NEMA 17HS2408 bipolar model (4.8 Volts, 0.6 Amps and 1.2 Kg/cm). A LPD3806-400BM-G5-24C AVP incremental rotary encoder of 400 PPR and 5V-24V. A DC-24V 24W motor with gear box CW/CCW (24V 150rpm). Also, a 16X2 LCD module for user interface, a EasyDriver - Stepper Motor Driver A3967 Microstepping board, a 4x4 hard Atmel Pic keyboard, and finally, 5V 12V 24V 15A Dual h-bridge DC module (CZB6721960). Each part and stages of the system is shown on figure 3, with their interconnection.

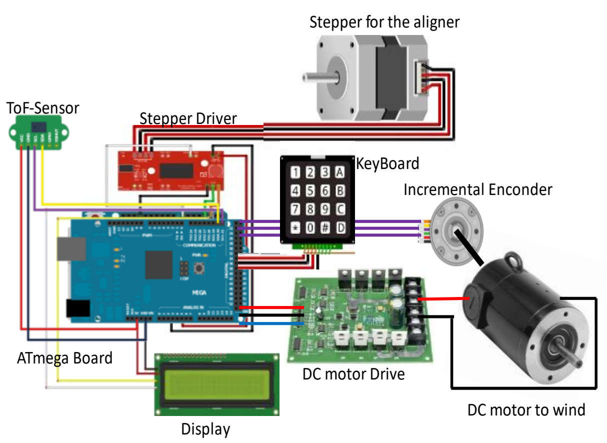

Figure 3 System stages

The complete equipment is presented in figure 4, where the system parts described previously are mounted on an aluminum mechanical structure. It was form with aluminum bosch framing, there exist a frame to support the optical fiber filament and is set on top of the structure. The position of that structure can be adjusted to stay in the middle of the spool, so this form is the aligning car moves in a specific gap.

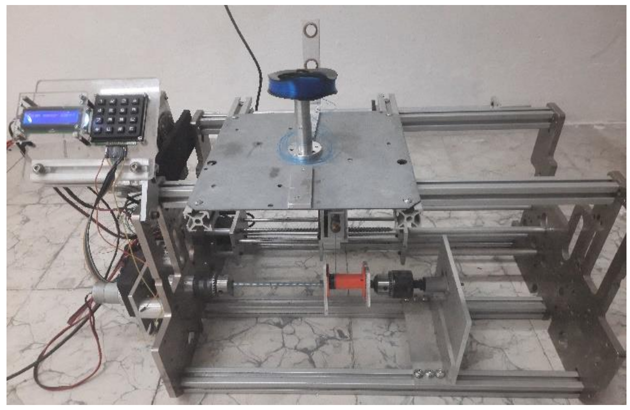

Figure 4 Real winding platform for optical fiber

Results

The moment when the system takes its time to calculate the number of layer and turs, allows the user to see if the winding can be conformed and the error is also calculated and validated with a specific length optical fiber filament, with a 100 meters filament. The extra material wounded around the spool was the 0.05 percent which was closed to the error estimated with the equation programmed in the microprocessor.

Conclusions

In conclusion, the system shows a low winding error, the use of fast development boards and the suitable mechanic platform allow a quick equipment construction, without a big budget and obtaining a good performance during its operation. Due to the modularity of the system, there are several future projects and opportunity areas, such as intelligent control algorithm, copper wire winding for transformer design using different gauge and vision control.

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