Research on Redesign and Manufacturing of an Automatic Roll Cutting Machine

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Abstract. *Textile-and-garment industry is one of the largest economic sectors in Vietnam, with 4000 enterprises and turnover of 20 billions USD/year. Therefore, designing and manufacturing are essential tasks for roll fabric cutting machines to serve the textile and garment industry. First of all, theoretical calculations are formulated for an automatic roll cutting machine. Then, simulations are conducted by a combination of MITcalc and Catia softwares. A prototype of fabric cutting machine is manufactured and experiments are implemented. The experimental results show that the machine stably works and overcomes the disadvantages of the popular cutting machines with the core-free roll on the market. The results also found that the size tolerance is achieved about ± 0.5 mm, and this ensures a good working quality. The designed machine has a significant contribution on the textile and garment area in decreasing the cost of the cutting process.*

Keywords

Textile, fabric cutting machine, simulation, fabrication.

1. Introduction

According to the Vietnam Textile and Apparel Association (VITAS), the textile is currently one of the largest economic sectors with 4000 enterprises. This sector can reach 20 billions USD per year, accounting for 15% of GDP of Vietnam [1]. Currently, Vietnam is in the top 5 exporting countries of the largest textile import in the world. Textile and garment products of Vietnam are present in 180 countries and regions around the world, such as the United States, Europe, and Japan.

The garment and textile industry are the second-largest export turnover in Vietnam. In 2019, the textile export value contributed to 16 percent of total GDP. According to VITAS, in 2019, Vietnam's garment and textile industry earned US$39 billion from exports, a year-on-year increase of over 8.3 percent. According to the Ministry of Industry and Trade of Vietnam, the export turnover of the textiles and apparel sector in the first 7 months of 2020 is estimated at 16.18 billion USD [1].

There are many different stages in the manufacturing process of industrial garment products, one of these is cutting fabric rolls to print labels, company logos, or cut fabric borders. Currently, the demand for roll cutting machines of textile and garment companies are huge, but most of the cutting machines are imported from abroad with a relatively high cost.

On the other hand, a numerous number of patents on fabric cutting machine have been invented, including number US Patent 695103 by Heny [2], US763804 of Seiberling [3], US879675 of Roos [4], US2186583 of Groh [5]. Most of all invented machines have the same disadvantages that they cannot cut non-core rolls. In the process of cutting fabric rolls, there are problems of material loss, uneven cutting, and wrong size cut.

More recently, new fabric manufacturing technologies have been increasingly developed such as laser cutting and water-jet thanks to an increased productivity, accuracy, and cutting quality [6]. Another machine was proposed to develop a textile and clothing manufacturing [7]. Before a real production, a computer-aided design was integrated with garment design [8]. Then, a fabric spreading and cutting were designed [9]. In order to add a color to garments, dyeing process was suggested [10].

For an automatic roll cloth cutting machine, the mentioned fabric machines are not still suitable. It needs an alternative technique. So, this paper suggests an automatic roll cloth cutting machine that can cut fabric rolls without core, specifically in the garment industry. It can effectively improve the sewing process and cost. Firstly, theoretical calculations are formulated for an automatic roll cutting machine. Next, simulations are performed by a combination of MITcalc and Catia softwares. A prototype of fabric cutting machine is manufactured and experiments are carried out.

2. Theory of operation

Nowadays, there have been many different operating principles of cutting fabric rolls. In this study, a cutting machine without core is proposed.

In accordance with the general requirements of the garment industry and the actual conditions of equipment, a technology of cutting fabric is suggested, as shown in Fig. 1. It includes four parts as follows: (1) fabric rollers, (2) disc cutter, (3) piston, and (4) the chassis. In this principle, a disc cutter with the roll of fabric outside the roll.

With this technology, users can cut both core and non-core rolls. They also can quickly attach the fabric roll to machine. The product can be immediately removed from the machine during the operation, and then it can cut the next product. Besides, it can eliminate the possibility of the product being skewered because the cloth roll is always perpendicular to the cutter. Lastly, this machine is convenient in inspection and maintenance.

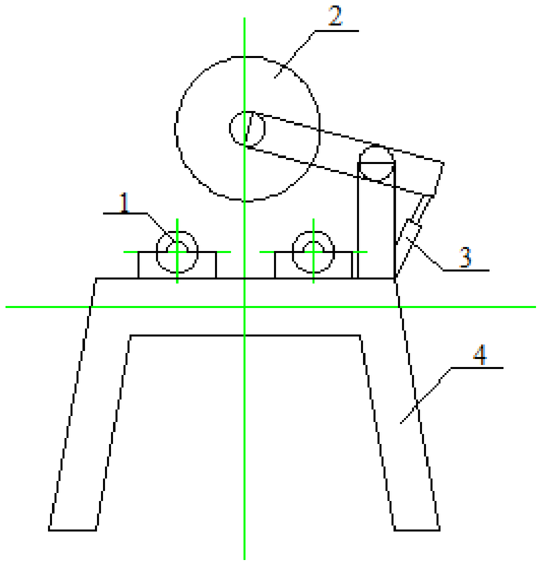


Fig. 1: Operating principle of Fabric cutting machine.

As given in Fig. 1, fabric rolls are placed on top of two fabric rollers (1) which are driven by a bottom motor via chain transmission. After the cutting position is determined, the disc cutter blade (2) is moved to the cutting position by means of a lead screw. The piston (3) moves the disc cutter blade in roll radial until the roll is completely cut.

3. Design and calculation construction

3.1. Calculation of lead screw

With the use of moving the disc cutting blade table, lead screw can use roller friction or slip friction. Today, the ball bearing roller friction nut is widely used, especially in precision moving mechanisms, control systems, critical force transmission parts, high efficiency, and friction force. It depends on the speed but the transmission is expensive. It is usually not self-braking. The lead screw is often used to transmit large force with non-high precision, low cost, and self-braking. With the not-so-high precision characteristics, the transmission type of sliding friction lead screw is chosen because clearance adjustment is relatively easy. Minor diameter, d_2, has been defined by Eq. (1) [11] as follows:

$$d_2 = \sqrt{\frac{F_a}{\pi \times [\rho]\, \psi_H \psi_h}} = \sqrt{\frac{F_{qt} + F_{ms}}{\pi \times [\rho]\, \psi_H \psi_h}} = \sqrt{\frac{570 + 600}{3.14 \times 8 \times 2.5 \times 0.5}} = 5.2 \text{ mm} \quad (1)$$

in which: d_2: minor diameter. $[p]$: permissible pressure (8 MPa).

In this study, $\psi_H = 2.5$; $\psi_h = 0.5$are chosen. Supposing that the quantity of table is 60 kg = 600 N, so coefficient of rolling friction $f = 0{,}95$. Velocity of table is chosen as 0.5 m/s. So, the acceleration of the table is 10m/s.

Since the screw length is chosen based on the gauge of 2000 mm, the screw thread diameter (d) can be increased by approximately 4 to 5 times so that stability check is not required. In this study, some parameters are chosen as d = 30 mm, step of screw thread $t = 6$ mm, and the d_2 = 24 mm. The working length of nut is determined as $l = 2d = 60$ mm.

3.2. Calculation and design of cutting structure

1) Calculation of the tool bearing shaft moment

The force exerted on the fabric is calculated as follows:

$$P_c = K \times f_c \times [\sigma]_b = 1.75 \times 1 \times 21.25 = 37.245 \text{ N} \quad (2)$$

This cutting force must overcome the limit of the breaking strength of the fabric.
In which: K is the reserve coefficient to increase the cutting ability of the tool. In this work, K value is chosen as 1.75. F_c is disc cutter section; $F_c = 1$ mm^2, and $[\sigma]_b = 21.25$ N/mm^2:

$$M_x = \frac{P_c \times D_{tb}}{2} = \frac{37.245 \times 500}{2} = 9311.25 \text{ N.mm} \quad (3)$$

where D_{tb} is maximum diameter of disc cutter (D_{tb}= 500 mm).

2) Calculation of the power on the tool carrier

The power on the tool carrier is computed as below:

$$M_x = 9.55 \times 10^6 \times \frac{N}{n} \text{ N.mm} \quad (4)$$

$$N = \frac{M_x \times n}{9.55 \times 10^6} = 1.365 \text{ KW} \quad (5)$$

in which

$$n = \frac{60 \times 1000 \times V_d}{\pi \times D_d} = 1400 \text{ rpm} \quad (6)$$

with $V_d = 37$ m/s, $D_d = 500$ mm
in which: M_x is the tool bearing shaft moment; N is the power of the tool carrier; n is velocity of disc cutting by rpm; V_d is velocity of disc cutting by m/s; and D_d is diameter of disc cutting.

3) Calculation of cutting motor power

The cutting motor power is calculated by:

$$N_{ct} = \frac{N}{\eta} = 1.5 \tag{7}$$

in which:
Machine powered by motor and V-belt, so $\eta = \eta_1^2 . \eta_2^2$
Look up the Table 2-1 [11]:
Belt driver efficiency, $= 0.96$
Ball bearing efficiency,$= 0.995$
So, $\eta = 0.96^2 \text{x} 0.995^2 = 0.91$
$N = 1.365$ KW, $\eta = 0.91$, N is the power of the tool carrier, and η is mechanical efficiency. Based on the above data, the electric motor for the cutter is selected as $N = 1.5$ KW and $n = 1450$ rounds/min.

4) Calculation of cutting tool carrier shaft

Hole diameter of Cutting tool is chosen as $d = 25.4$ mm and the bearing shaft diameter is about 30 mm. MITCalc software is utilized to calculate the durability test for shaft with length L of 260 mm and outside diameter D_n of 32 mm. The result of the minimum dynamic safety factor is 6.13 and deflection the largest is approximately 0.0111 mm. So, the shaft ensures safety conditions. Figure 2 shows the results of calculation and testing of tool bearing shaft using MITcalc software.

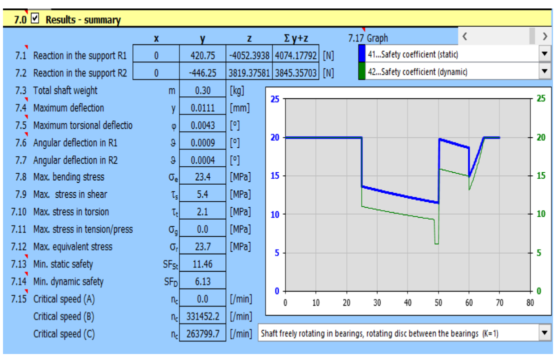


Fig. 2: Calculation and testing of tool bearing shaft using MITcalc software.

5) Calculation and test of the durability of the chassis

When the cloth cutting machine works, the cutting machine frame is affected by tightening forces. The force of cutting causes the machine frame to bend and cutting force causes the machine frame to bend horizontally. Meanwhile, the shearing force and weight of the components are placed on the machine cause the chassis to bend down. As shown in Fig. 2, a load of 70 kg is placed on the guide body of the cutter assembly. A maximum load of about 100 kg is applied to the two ends of the machine frame. When the machine was operated, the main force acting on the object from the cutting tool will be in the frame of the cutting tool and the shaft end. Therefore, for the computation of safety factor and displacement, the load should be put in three positions in Fig. 3. It illustrates load and simulation results of the chassis.

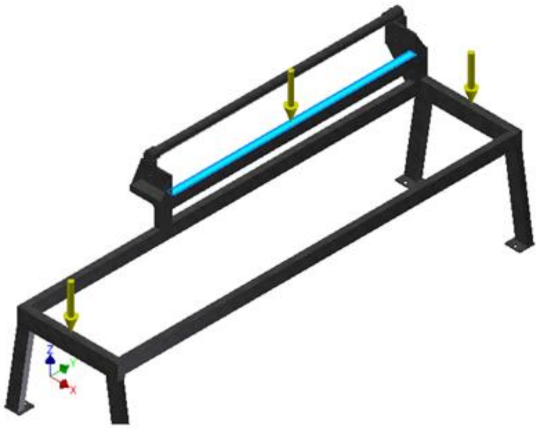
In Fig. 3b, the results show that the maximum von Mise stress is 19.64 MPa. The maximum displacement of the frame is 0.3899 mm, as depicted in Fig. 3c. The minimum safety factor of the chassis is equal to 3, as shown in Fig. 3d. Thus, with the design of the chassis as a rectangular steel box of CT3, it meets the safety requirements.

4. Test performance

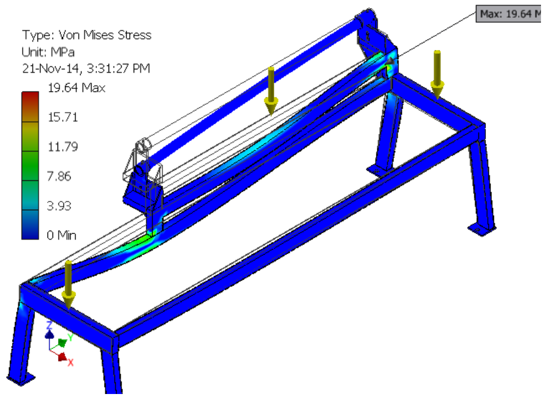
4.1. Experimental arrangement

After being assembled, the cutting machine is checked and run with no fabric roll. This is allowed to test the cutting with a number of different fabrics. It can test the durability of the structure, calibrate the machine, and select the machining parameters. Figure 4 fully describes the fabric cutting machine which is assembled on Catia software and actual machine.

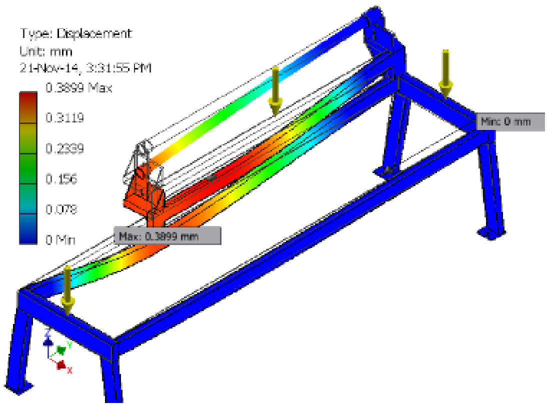
Fabric cutting machine technological parameters include as follows: cutting tool speed (V_{dc}), cloth roll speed (V_{tq}), and cutting time (t_c). According to technological parameters from the manufacturers of cutting machines, it can deter-



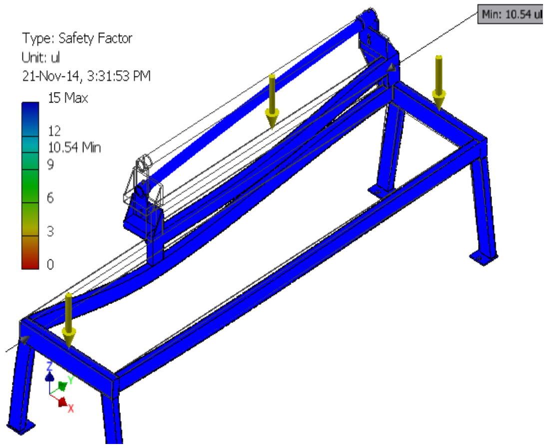
(a)



(b) Von Mises stress

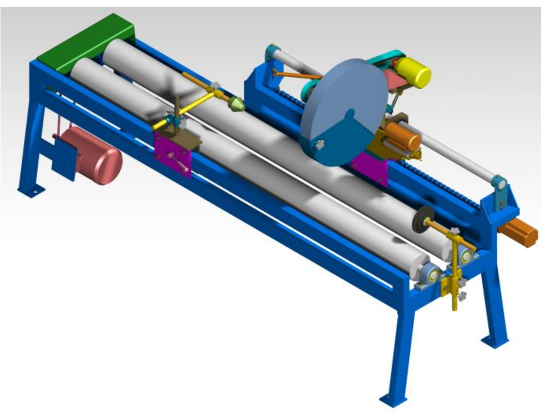


(c)



(d)

Fig. 3: Results of load analysis on the chassis: (a) load, (b) von Mise stress, (c) displacement, (d) safety factor.



(a)

(b)

Fig. 4: Fabric cutting machine fully assembled: (a) Catia software, and (b) actual machine.

mine the following parameters as:

$$V_{dcMax} = 1600 \text{ (rpm)} = \frac{\pi.D.n}{60.1000} = 41.8 \text{ (m/s)} \quad (8)$$

$$V_{tqMax} = 60 \text{ (rpm)} = \frac{\pi.D.n}{60.1000} = 0.4 \text{ (m/s)} \quad (9)$$

The results found that the fabric roll speed is about 0.9% compared to cutter speed. So, it doesn't affect too much the cutting process. Fabric rollers only have the meaning of rotating fabric roll so that the cutter can cut all rolls of fabric and just go of the roll diameter. According to the experiments, the fixed fabric winding speed, V_{tq}, is determined as 30 rpm.

Before preparing for automatic cutting, the experiment is carried out with two manual and automatic cutting modes. The manual cutting mode is used experiment to check the rigidity of the manual cutting device and the operation of other equipment. In addition, in the manual cutting mode, the longest time is 120 seconds. Cutting experiment was performed with 100% polyester fabric with diameter, D, of 150 mm. Manual cutting results show that the range of cutting tool speeds from 100 rpm to 800 rpm has been achieved. However, with too long cutting time (more than 120 seconds), the cross-section and the cutting knife are subjected to a great friction. This results in a large heat generation, unsmooth cross-section, burning and sticking in some places.

4.2. Results and discussion

Test results of manual cutting and automatic cutting are given in Tabs. 1 and 2, respectively.

After the testing operation with two manual and automatic cutting modes, the results show that the machine structure works stably and the chassis is strong enough. Besides, the system is a precise control, the control interface is easy and reasonable. The cutting speed ratings are used for the tested fabrics as follows: V_{dc}= 100 rpm - 800 rpm, V_{tq}= 30 rpm, cutting time t= 10 s – 40 s, and diameters D= 150 mm - 230 mm.

Compare with the same machine in the market, it just has been half the price, as given in Tab. 3.

Tab. 1: Test results with manual cutting.

No	Descriptions	V_{dc} (rpm)	t_{dc} (s)	Result
1	Fabric 100% Polyester	300	30	O
	D= 230 mm	700	20	O
2	Fabric 95.3% Cotton + 4.7% Spandex	500	20	O
	D= 180 mm	800	20	O
3	Fabric 100% Polyester	100	40	O
	D= 150 mm	600	120	X

Tab. 2: Test results with automatic cutting.

No	Descriptions	Vdc (rpm)	tdc (s)	Result
1	Fabric 100% Polyester D= 230 mm	100	40	O
		300	30	O
		500	20	O
		700	10	O
2	Fabric 95.3% Cotton + 4.7% Spandex D= 180 mm	200	40	O
		400	30	O
		600	20	O
		800	10	O
3	Fabric PE 100% Polyester D= 150 mm	100	40	O
		300	30	O
		500	20	O
		700	10	O

(Note: O - Pass; X – Failure. The result is certified by the Textile Experiment Center of the Textile Institute in Ho Chi Minh City)

5. Conclusions

Based on the theoretical basis and the actual fabrication, testing the automatic roll fabric cutting machine has been manufactured to meet the initial design requirements. The results are drawn as follows:

- The results indicated that the machine structure works stably and the chassis is strong enough.

- The results indicated that the range of cutting tool speeds from 100 rpm to 800 rpm has been achieved.

Tab. 3: Compare the quality charatetistics of the proposed machine with the same machine in the market.

No	Details	LQ-00 [12]	The proposed machine
1	Machine shaft width	1600 mm	2650 mm
2	Max cutting	Ø380 mm	Ø400 mm
3	Cutting core	Ø1-3 inch	N/A
4	Cutting precision	±0.1 mm	±0.5 mm
5	Diameter of circular blade	Ø450 mm	Ø500 mm
6	Power	5.5 KW	5.5 KW
7	Price	US $11,000-13,500	US $5,000

- The cutting speed ratings were found for the tested fabrics as follows: $V_{dc}=$ 100 rpm - 800 rpm, $V_{tq}=$ 30 rpm, cutting time $t=$ 10 s – 40 s, and diameters $D=$ 150 mm - 230 mm.

- The machine was designed with a guaranteed aesthetic appearance.

- The machine used a PLC programmable control system.

- The adjustment parts are arranged appropriately for easy and quick adjustment.

- The safety system in the machine is fully designed and ensuring the safety of workers when working with the machine.

- Lastly, this study also significantly contributes in reducing the cost of the machine.

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