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DESIGN AND DEVELOPMENT OF PNEUMATIC MECHANISM FOR PRIMARY MOTIONS OF 'ASO-OKE' WEAVING MACHINE

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Abstract

This study is on design and development of a pneumatic system mechanism for primary motions (shedding, weft insertion and beat-up operations) in weaving machine for production of "Aso-Oke". The present study objective is to improve the current performance efficiency of the treadle loom machine where 65 cycles of weft insertions per minute can be achieved when used by the local weavers. Three air cylinders and a compressor selection design for shedding; weft insertion and beat-up operations were based on Pascal's law with load factors including losses considered. Design results recommended selection of a 3 HP compressor and air cylinders operating at a pressure of 5 bar. Likewise the test results revealed that the mechanism could make only 172 weft insertion cycles per minute against 260 cycles design target. In addition, the present design is compact, thus requires smaller space and weaves up to 300 mm width fabric against the existing 175 mm width.

Keywords: Aso-Oke, Primary motions, Weaving machine, Pneumatic mechanism

Nomenclature

θ	Angle makes by a division of warp yarns with horizontal line during shedding, (°)
π	Mathematical constant
a	Acceleration due to gravity, (ms^{-2})
C_F	Air consumption during forward stroke of the air cylinder, ($l/_{stroke}$)
C_R	Air consumption during returning stroke of the air cylinder, ($l/_{stroke}$)
D	Bore size of the air cylinder, (mm)
F	Force required to push the air cylinder, (N)
F_f	Frictional force due to yarn-to- yarn, (N)
F_y	Tension of each division of warp yarns not in shedding section during shedding, (N)
L	Air cylinder stroke, (mm)
M	Mass of the beater, (Kg)
P	Operating pressure, (bar)
S	Distance covers by beater (Reed), (m)
T_{h1}, T_{h2}	Force required to create the shed, (N)
T_a , T_b	Tension of each division of warp yarns during shedding, (N)
W_h	Weight of the heald with its frame, (N)

1. Introduction

Textiles in Nigeria have provided varieties of designs and patterns (both in colours and qualities) to meet the fashion taste and requirements by which certain ethnic groups are identified (Chinedu *et al*., 2013) One such cloth is Aso Oke which is a long narrow fabric, joined side-by-side to form a wider cloth, and sewn for various dressing styles usually used for festivals and ceremonies among Yoruba tribe in Africa (Ajila *et al.*, 2016 and Olutayo *et al.*, 2011). Despite Nigeria's colonial experience which resulted in importation of cheaper foreign textiles, traditional textiles are still kept alive through their production, use, sale, and marketing (Arethar, 2007 and Ademuleya, 2014). Olutayo and Akanle (2009) from their studies realized that the textile industry can be revitalized and used as tool for national development especially as it was discovered that sustainable ligaments exist among traditional, cultural, consumption and manufacturing economies within the nation.

Technological application of fluids under pressure in transmission and control of power is becoming increasingly used in industries. The extensive use of such systems to transmit power is due to the fact that properly constructed fluid power systems possess a number of favourable characteristics. They eliminate the need for complicated systems of gears, cams, and levers. Also, they transmit motion without the slack or delay inherent in the use of solid machine elements. Fluid power is a term covering both pneumatic and hydraulic power. Pneumatic deal with the use of compressed air as the fluid whilst hydraulic power covers the use of oils and other liquids. Pneumatic systems are very common, and have much in common with hydraulic systems with a few key differences. Pneumatic systems respond very quickly, and are commonly used for low force applications in many locations on the factory floor.

According to Alssarraf *et al.* (2007), the advent of electro-pneumatic Pulse with Modulation came around in the 1980's in the works of Noritsugu, and Morita. In 1985, both parties separately implemented such a system in a pneumatic manipulator and they found that it is possible to obtain continuous feedback control without the use of servo valves (Lai *et al.,* 1988). In addition, Lai *et al.* (1988) utilized the Pulse with Modulation method and they were able to achieve good position of accuracy with a pneumatic actuator without using any mechanical stops.

Knowledge and understanding of hydraulic and pneumatic systems and their components make engineers better qualified to carry out their jobs in industries. Textile industries are not left out of this technological development. This industry is traditionally regarded as a labour-intensive industry developed on the basis of an abundant labour supply. Textile generally involves five processes, namely; fiber production, spinning, warping, weaving and sewing. This work focus on the design and development of a cloth weaving based machine.

Weaving is a mechanism through which two sets of yarns called warp and weft are interlaced together to form fabric by the machine technically called loom (Akinwonmi, 2011). Looms are classified into four groups according to their weft insertion systems: shuttle, projectile, rapier and jet (air and water jet) looms (Alaka, 2014). Of these groups, the shuttle and projectile weft systems have reached the term of their economic life because of their low weaving velocity while water jet system does not have wide application in practice (Kayacan *et al.*, 2004). Historically, loom has undergone significant modifications, but the basic principles and operations remain the same. Warp yarns are held taut within the loom, and weft yarns inserted and pushed into place to make the fabric. The motions on loom are classified into primary, secondary and auxiliary motions. The primary motions are shedding, weft inserting and beating-up; secondary motions include let-off and take-up while auxiliary motions consist of weft stop, brake, warp stop and warp protector. This paper is restricted to only primary motions. Initially, shuttle loom is used for making fabric. During the industrial revolution, mass production high speed looms were developed. Today, the industries use modern looms like projectile, rapier, air jet and water jet looms. These looms are highly speedy and production capacity is very high. The modern loom consists of two beams, a warp beam and a cloth or fabric beam, holding the warp yarns between them. Warp yarn that is sufficient for length, width, and density of the fabric to be woven is wound carefully onto a warp beam.

2. Materials and Methods

The design of pneumatically operated system for the primary motion of weaving looms was based on data collected during a visitation paid to local weavers at Iseyin, Oyo State, Nigeria. The weavers were using treadle loom and hand loom in the production of narrow fabric weaves, locally called "Aso-Oke". Various motions of the loom were identified, studied and noted. These motions were not quite different from those of looms used in production of other types of fabric but the mechanisms through which the forces were generated differed and the machine was operated by hands and feet. In this design, air cylinders of various sizes determined on the basis of standard graphs by SMC catalogue, were employed as actuators, while compressed air generated the forces based on the standard Tables of Compressed Air and Gas Institute (CAGR, 2002).

Figure 1 and Table 1 show the criteria considered in establishing the design concepts of the pneumatic circuit.

2.1 Sizing of Pneumatic Cylinders for Shedding, Weft-Insertion and Beating-Up Operations

Determination of appropriate size of a cylinder (either pneumatic or hydraulic) for a particular operation depends on two key factors, namely:

a. Total evaluation of the load: This load is not limited to the basic load to be moved by the cylinder, but also includes any friction and force to accelerate the load, force needed to exhaust the air from other end of the cylinder through the attached lines, control valve and any other loads or force required to move the load as desired.

b. Assumption of working pressure: This pressure is the one seen at the cylinder's piston when the motion is taking place. It should be noted that the cylinder's pressure (Figure 2) is less than that of the actual system pressure due to the flow losses in lines and valves. Then, the cylinder size is calculated using Pascal's law,

$$\text{Force (F)} = \text{Pressure (P)} \times \text{Area (A)} \quad (1)$$

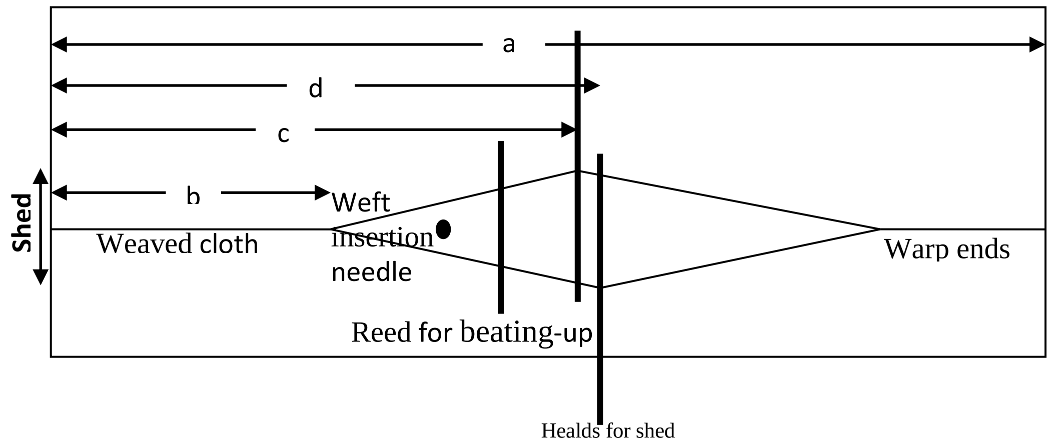

Figure 1: Various distar eaving section

Table 1: Details of the parameters in figure 1 measured at different weavers' locations

	Material								
Parameter	Wool 1	Wool 2	Cotton 1	Cotton 2	Cotton 3	Flax 1	Flax 2	Flax 3	Silk
No. of Ends	180	170	150	160	155	200	140	185	365
Force (N)	40	38	38	40	40	40	25	38	60
Shed (cm)	9	9	13	8.5	9	8.5	11	11	7.5
a (cm)	65	64	65	65	65	65	65	65	66
b (cm)	21	28	30	18	25	20	16	23	17
c (cm)	23	12	19	16	14	19	17	19	17
d (cm)	26	15	23	17	17	21	19	22	19
Width of the Fabric (inch)	7	6.5	7	7	6.5	7	6.5	7	7
No. of cycles per minute	56	58	60	58	62	60	65	63	60
Age (yrs)	35	32	32	22	23	28	31	26	46

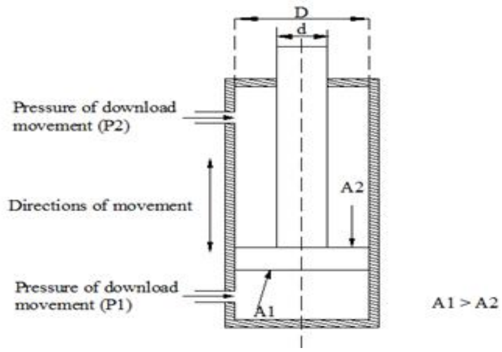

Figure 2: Double acting cylinder showing parameters of the cylinder

2.2 Evaluation of Total Load for each Operation

2.2.1 Shedding

The nature and type of forces involved in the shedding operation are diagrammatically represented in Figure 3.

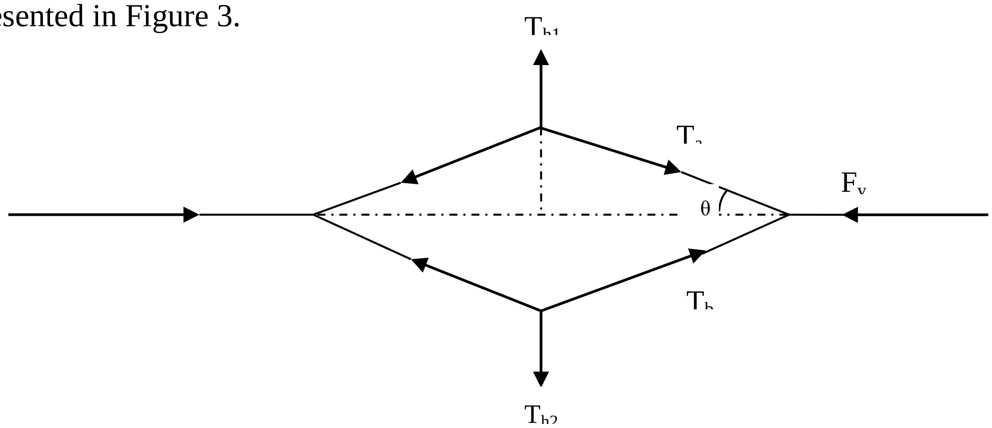

Figure 3: Analysis of shedding forces

$$\theta = \tan^{-1}\left(\frac{60}{100}\right) = 31^0 \quad (2)$$

$$T_a = T_b = \frac{F_y}{\cos\theta} \quad (3)$$

$$= \frac{245}{\cos 31^0} = 285.825 \text{ N}$$

Also,

$$T_{h1} = T_{h2} = T_a \sin\theta \quad (4)$$

$$= 285.825 \sin 31^0$$

= 147.21N

T_{h1} and T_{h2} are the forces required to divide the warp yarns into two and create the shed, the weight of the heald with its frame, $W_h = 4.51$ N, and yarn-to-yarn frictional force $F_f = T_h x0.3 =$ 147.21x0.3 = 44.16N.

According to Vildan *et al.* (2013) appropriate inter-yarn frictional coefficient is 0.3.

Therefore, the force required to create the shed = $T_{h1} + W_h + F_f$ (5)

= 147.21 + 4.51 + 44.16

= 195.883, approximated to 196 N.

With assumption of 5 bar working pressure,

From Pascal's law: $F = P\frac{\pi D^2}{4}$ (6)

Then, $D = \sqrt{\frac{4F}{\pi P}}$ (7)

$D = \sqrt{\frac{4x196}{\pi x5x10^5}}$ = 0.0223 m

= 22.3 mm

Two (2) Ø25 mm bore size cylinder, each with 60 mm stroke are to be used.

2.2.2 Weft Insertion

There are three cylinders to be selected for this operation: one to be used for the main insertion operation, one acts as a hook to retain the newly inserted weft while the third one is meant for reciprocating of the one serving as hook.

The force required by the weft insertion needle to unwind the weft yarn from three cones is 13.5N. With assumption of 5bar working pressure, using equation (7), we have:

$D = \sqrt{\frac{4x13.5}{\pi x5x10^5}}$ = 0.00586 m

= 5.86 mm, approximated to 6 mm

Though, the remaining two cylinders do not require up to 13.5 N force, but the same size of bores are to be selected since 6 mm is the smallest bore size commercially available.

2.2.3 Beating-up

Since the beating-up operation was carried out at the returning stroke of the piston, then,

$F = P\frac{\pi(D^2-d^2)}{4}$ (8)

Where: d = piston rod diameter.

Since the bore size, D, is the same, one can apply equation (7), so that,

$$D = \sqrt{\frac{4F}{\pi P}} \quad (9)$$

To analyse the force require to compress the weft from point of insertion to the fell of weft, we apply the following relations,

$$F = ma, \quad (10)$$

$$S = ut + \frac{1}{2}at^2 \quad (11)$$

S = 0.15 m; u = 0; t = 0.05 s (assigned time)

Then, $S = \frac{1}{2}at^2$ (12)

Thus, $0.15 = \frac{1}{2}xax0.05^2$ leading to:

$a = 120\ ms^{-2}$

The mass of the reed (beater), M = 0.72 Kg

Then, the force F_b required to accelerate the reed = 0.72 x 120

= 86.40 N

Also, the frictional force F_r due to steel against yarn = 86.4 x 0.23

= 19.87N

Therefore, total force needs to compress the weft yarn to fell of weft = $F_b + F_r$

= 86.4 + 19.87

= 106.27N

Now, from equation (11);

$$D = \sqrt{\frac{4x106.27}{\pi x5x10^5}} = 0.0165\text{m}$$

= 16.5 mm, approximated to 17 mm

Hence, a 17 mm diameter bore size with 155 mm stroke cylinder is recommended for this operation.

2.3 Selection of Compressor

The size of compressor was determined based on two major factors:

a. Maximum required operating pressure: The operating pressure has been assumed to be 5 bar but the air compressor to be selected must be rated over this operating pressure by at least 30% due to losses that are expected (minimally) in the air tubes and valves.

b. Maximum required air usage: This is addition of air required by only cylinders operating simultaneously and not by all cylinders on the machine as this will inflate the capacity of the compressor, hence increase the running cost.

Determination of air needed by each of the cylinders has to do with air required during the forward stroke, returning stroke and the one in the piping between the cylinders and the switching valves, each time the switching valves operate.

This could be done either by using:

i. Formulae

C_F = Piston area x (Operating pressure + 1.013) x stroke (13)

$= \frac{\pi D^2}{4}(P + 1.013)\frac{L}{1000}$ $({}^{l}/_{stroke})$ and

C_R = Piston area x (Operating pressure + 1.013) x Stroke (14)

$=\frac{\pi(D^2 - d^2}{4} * (P + 1.013) * \frac{L}{1000})$

Where, C_F = air consumption during forward stroke,$({}^{l}/_{stroke})$, C_R = air consumption during returning stroke$({}^{l}/_{stroke})$, D, d and L (in cm),P (in bar)

ii. Graphical method

This method which was adopted in this work could be found in SMC catalogue. Using graph 12 of the SMC catalogue, the air consumed by each of the cylinders could be obtained as shown in Table 2.

Table 2: Air consumed by each of the cylinders

Cylinder for	Operating Pressure (bar)	Cylinder Stroke (mm)	Cylinder Bore (mm)	Air Consumption $({}^{l}/_{cycle})$	Air Usage $({}^{l}/_{min})$
Shedding	5	60	25	0.25 (x2)	65 (x2) = 130.00
Reed	5	155	17	0.360	93.60
Weft 1	5	300	6	0.080	20.80
Weft 2	5	100	6	0.025	6.50
Weft 3	5	50	6	0.012	3.12

Note: Air usage ${}^{l}/_{min}$ = 260 x air consumption $({}^{l}/_{cycle})$

Number of weft insertion cycle per minute = 260.

Also from graph 13 of SMC catalogue, the air consumed by the tube that connects each cylinder to the valves could be obtained as shown in the Table 3.

Table 3: Air consumes by the tube that connects each cylinder to the valve

Cylinder for	Operating Pressure (bar)	Piping Length (m)	Pipe Bore (mm)	Air Consumption (l)
Shedding	5	0.6	8	0.28
Reed	5	0.8	8	0.40
Weft 1	5	0.7	8	0.33
Weft 2	5	0.7	8	0.15
Weft 3	5	0.7	8	0.15
Compressor	5	1.0	8	0.50

Hence, the total sum of air quantity to be consumed in one minute operation is addition of 161.72 litres and 4.97 litres, which is 166.69 litres. If 30% of this total is added for buffer in anticipation of unknown and uncommon usage of the compressor, then the need can be approximated to $217\, litres / cycle$. Converting this value to Cubic Feet per Minute (cfm) of air delivery for the purpose of compressor selection, we have $217\, litres / cycle = 7.55\, cfm$.

On the compressor selector chart, Compressed Air and Gas Institute [13], under the column "Continuous Operation" and cfm ranges 7.7 – 10.2 against one-stage, the compressor required is a 3HP compressor.

2.4 Development of Pneumatic System

In order to get the proper workability of the pneumatic components, a model was created and ran with FluidSim-P software of the Festo Pneumatic Simulation Software. In the first created model, a control valve was connected to each of the air cylinders, that is, six control valves to six air cylinders. It was later discovered (during testing of the model) that only one control valve could be used to control two cylinders for shed operation, Figure 4. As a result of this discovery, the number of control valves used in the development of the pneumatic circuit reduced by one, hence reduced the cost of production. Then, the mechanical component(Figure 5) was constructed, where each of the cylinders was positioned appropriately, the control valves were also positioned and bolted onto the board, then, the connections were done with the air compressor, control valves and the cylinders with air tubes of appropriate length as shown in Figure 6.

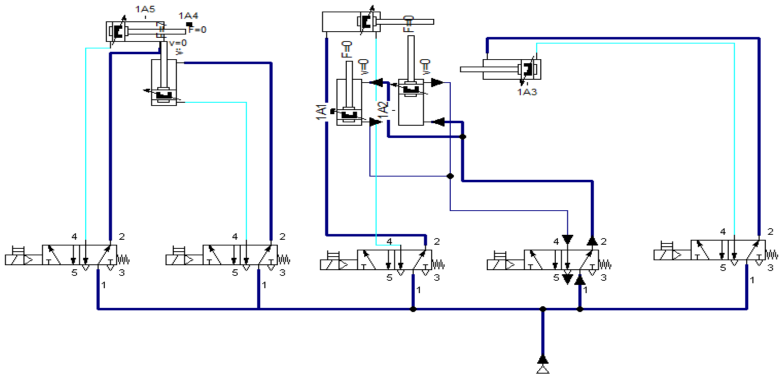

Figure 4: Pneumatic Circuit for the three motions, using FluidSIM-P

Figure 5: Mechanical components for the three motions

Figure 6: Connection of Mechanical components with pneumatic and electrical circuits for the three motions

2.5 Testing

After the development of the system, various tests were carried-out to ensure that the system functions as desired.

2.5.1 Manual Test
Each mechanism was connected separately to compressor (one after the other) and powered. It was observed that each mechanism moved as expected, only that the number of weft insertion per minute could not be determined yet.

2.5.2 Powered Test
Here, the mechanisms (that is, mechanical, pneumatic and electrical mechanisms) were connected and the test was carried out.

3. Results and Discussion
The weft insertion needle of this mechanism is made such that the machine can weave 300 mm width Aso Oke against the existing 175 mm.

The test carried out revealed that control valves respond according to the expected sequential order as shown in Figure 7, and these led to expected sequential order of correct performance of each of the cylinders.

However, going by the aims and objectives of the study whereby the machine is targeted to make 260 weft cycles per minute of operation, that is, 0.23 seconds required per cycle of operation, the new machine mechanism however made maximum of 172 weft cycles per minute, that is, 0.35 seconds required per cycle of operation.

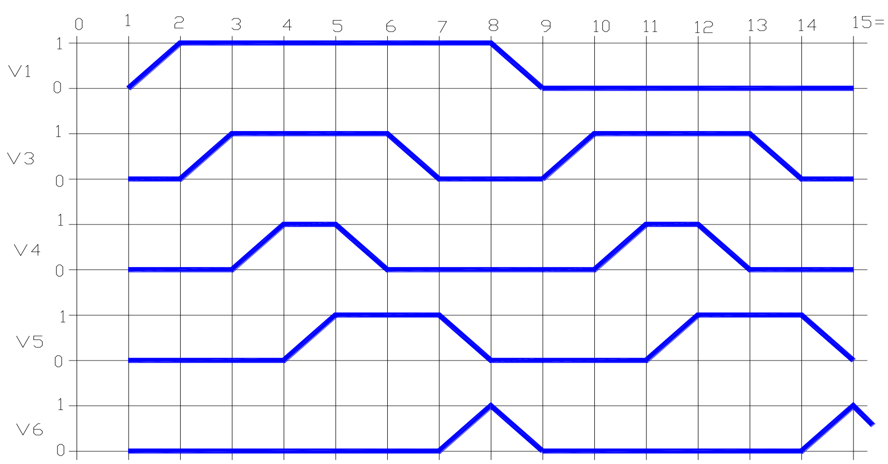

Figure 7: Valve controls' sequential circuit

4. Conclusion
A pneumatic control machine system has been designed and developed for primary motions of Aso Oke weaving machine. Although, the objective of the present study is to make 260 cycles of weft insertion per minute, only 172 cycles per minute was achieved, which constitutes 67.7% success. Thus, there is no doubt that introducing this mechanism into Aso Oke weaving activities can drastically increased its productivity while reducing the time cost, labour cost and the space often needed by the operators of the local weaving machines. Therefore its integration into

activities of Aso-Oke weaving is hereby recommended to alleviate challenges usually faced by the Aso-Oke weavers.

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