2

Weaving

2.1 Questions

1. Find the expression of production in m/h, m^2/h and kg/h of a fabric having E ends/dm and P picks/dm on a loom running at 'n' rpm with an effective reed width of R m. If warp count is N_1 tex and weft count is N_2 tex then calculate the corresponding fabric areal density.

2. Find the expression of fabric areal density in g/m^2 of a fabric woven with 'e' ends/inch and 'p' picks/per inch, employing yarns of English cotton count N_{1e} and N_{2e} in warp and weft directions crimped by C_1 and C_2% respectively.

3. Calculate production in m/h and kg/h of a plain loom running at 200 rpm with 90% efficiency at an effective weft insertion rate of 400 m/min employing a reed of count 60 with two threads drawn in each dent and a change wheel of 40 on a standard seven wheel take up motion employing warp and weft yarns of count 25 and 12 N_e respectively, each getting crimped by 4% in fabric.

4. Calculate the instantaneous power required to accelerate a 30 cm long shuttle of 0.5 kg mass over a distance of 10 cm from rest to a velocity high enough for free flight across a 2 m wide shed during 150^0 crank displacement of a loom running at weft insertion rate of 400 m/min. By how much can the reed be made wider if the flight duration is increased to 200^0?

5. For a 1.5 times greater duration of passage of weft yarn and a ten times lower mass of weft carrier, by how much could the WIR of a gripper loom be higher than that of a shuttle loom if the picking power is held constant.

6. Compare the mechanics of conventional shuttle propulsion with that of gripper shuttle propulsion.

7. The following are given for a gripper shuttle loom
   - Mass of gripper = 0.04 kg
   - Shear rigidity of torsion rod = $8163.\ 10^7$ N/m^2
   - Length of torsion rod = 0.72 m
   - Polar moment of inertia of torsion rod = 5.10^{-9} m^4
   - Maximum angle of deformation of torsion rod = 0.5 radians

   Calculate the maximum velocity that the gripper may attain if the entire energy of torsion rod is transmitted to the gripper. What are the mechanical constraints to achieving a high percentage of energy utilization?

8. Calculate the maximum velocity attained by Dewas and Gabler types of rapier both inserting single pick of weft assuming
   - The WIR to be 1200 m/min for a 3m wide loom
   - Rapiers remain within shed for two thirds of a cycle executing simple harmonic motion while starting to move at 0^0 position of crank

9. Why rapier looms operating with tip to tip transfer principle are more suitable for production of complex fabrics as opposed to other forms of weft insertion systems? Would this hold true for loop transfer systems as well?

10. Considering the conventional blowing profile of relay jets shown in Fig. 9.24 calculate (a) air consumption per loom cycle and (b) the range of yarn length under influence of the jets during one cycle if WIR of the loom = 960 m/min and the relay jets are spaced 100 mm apart, each blowing 6 liter of air per minute of operation.

11. An air jet machine of width 4m operating at 650 rpm has 10 relay jets per meter of reed width. The weft yarn takes 150 degrees to cross the entire reed width and the relay jets

blow over a period of 180 degrees of main shaft rotation. If 100 cc of air is blown by each jet per second and if a minimum length of 250 mm of weft yarn has always to be under the influence of air jet then work out the total air consumed by the valves controlling the relay jets in a shift of 8 hours at 98% loom efficiency, if a distribution of 2 jets per valve is assumed over the entire reed width.

12. Assuming that a 3m wide air jet loom is equipped with 42 relay nozzles controlled by 11 valves work out the blowing sequence of different valves for an optimal performance. Find out the periodicity of variation in length of yarn controlled by the jets.

13. Would the air consumption of an air jet loom weaving cotton yarns be
    - Greater for finer yarns?
    - Less for highly twisted yarns?

    Justify your answer.

14. Considering the sectional view of a jet nozzle explain how the pressure energy of air gets converted to kinetic energy. Under what condition does the tip of weft get sucked into yarn tube?

15. Considering typical velocity profiles of an air jet and a water jet emerging from main nozzle as function of angular displacement of the main shaft (Figs. 9.17 and 9.26) explain reasons behind dissimilarities between the two.

16. Explain reasons behind the following observations
    - A modern gripper loom exhibits a much lower WIR but much higher maximum possible reed width as compared to a modern jet loom
    - The tip of water jet emanating from a nozzle exhibits a fist like bump during its motion beyond the laminar zone
    - The rapier system of weft insertion is preferred for weaving fabrics requiring a wide range of weft yarns – in terms of count and material – in the same fabric

- The peak weft tension in a jet loom is recorded when the tip of weft nears its end of flight path
- Dewas system of rapier is more popular than Gabler

17 Compare the relative merits of the four types of shuttleless looms in respect of

- Power consumption in kWh/kg of fabric produced
- Maximum possible reed width
- Control on weft tension during its insertion

18 Name the salient features of a modern air jet loom that has contributed to its growing dominance of the shuttleless loom sector. Which features of rapier, projectile and water jet insertion principles o not permit such a development?

19 Considering the equations governing the motions of projectile and that of the weft dragged by air jet explain the difference in nature of velocity profiles of corresponding weft yarns

20 Keeping the overall trend in development of shuttleless looms in view, justify the growing commercial popularity of air jet and rapier looms.

21 Explain the principle governing leno formation by rotating disc method.

22 What are the structural differences between a leno formed by half rotation of disc as compared to the one formed by full rotation?

23 Given that WIR = k. $R^{0.5}$ and C=M+N.R where WIR=weft insertion rate in m/min, R=reed width in meters, C= loom cost and M & N are two constants find out the condition under which it would be more profitable (in terms of cost of investment per square meter of fabric produced) to purchase one loom of width 2R as compared to two looms each of width R.

2.2 Answers

1 At 'n' rpm the number of picks of length 'R' m woven per hour = 60 n

Therefore

Total length of weft yarn woven per hour = 60 [n R] m = 60[WIR] m

Total length of warp woven per hour = 10 E R 60 [n/10P] [1 + (C_1/100)] m

= 60 [WIR] [E/P] [1 + (C_1/100)] m

Where

C_1 = % warp crimp

WIR = Weft insertion rate in m/min

And

Total length of fabric woven per hour = [60 n/ 10 P] = 6 n/P m

Hence lower the pick density in fabric higher is the production in terms of fabric length.

The fabric width

F = R/ [1+ (C_2/100)]

Where

C_2 = % weft crimp

Hence total area of fabric woven per hour

= [6 n/P] x R/ [1+ (C_2/100)]

= 6[WIR][{1+ (C_2/100)}/P] m^2/h

Hence lower the weft crimp and lower the pick density in fabric higher is the production in terms of area of fabric.

For warp count of K_1 tex the weight in grams of warp yarn woven per hour

= [K_1/1000][60 WIR] [E/P] [1 + (C_1/100)] g

Similarly the weight in grams of weft yarn of K_2 tex woven per hour

= [K_2/1000][60 WIR]

Hence fabric production in kg/h is

[60 WIR]{K_2+K_1 [E/P] [1 + (C_1/100)]} x 10^{-6}

Hence fabric production in kg/h goes up with higher warp crimp, heavier yarns and higher ratio of [E/P]. Evidently higher weft insertion rate contributes to increase all three production parameters.

In terms of fabric sett therefore one should aim for highest possible ratio of [E/P], lowest possible value of weft crimp and highest possible value of warp crimp for increasing woven fabric production for any given combination of warp and weft yarns.

2. Length of one warp yarn in 1 m length of fabric is

$$[1 + 0.01\ C_1]\ m$$

Length of one weft yarn in 1 m width of fabric is

$$[1 + 0.01\ C_2]\ m$$

Total length of weft yarn in 1 m length of fabric is

$$39.37\ p\ [1 + 0.01\ C_2]\ m$$

Total length of warp yarn in 1 m width of fabric is

$$39.37\ e\ [1 + 0.01\ C_1]\ m$$

Mass of weft in 1 m length of fabric is

$$[592/N_2]\ 39.37\ p\ [1 + 0.01\ C_2] \times 10^{-3}$$

Mass of warp in 1 m width of fabric is

$$[592/N_1]\ 39.37\ e\ [1 + 0.01\ C_1] \times 10^{-3}\ m$$

Areal density of fabric in g/m^2 is

$$23.3\ \{[p/N_2]\ [1 + 0.01\ C_2] + [e/N_1]\ [1 + 0.01\ C_1]\}$$

3 Number of picks inserted per hour at 90% efficiency on a 200 rpm loom is

$$200 \times 60 \times 0.9 = 10{,}800$$

For a fabric with 40 picks/inch, insertion of 10,800 picks result in production of

$$[10{,}800/40 \times 39.37] = 6.858\ m/h$$

With WIR of 400 m/min at loom rpm of 200, the effective reed width is 2m.

Total number of warp yarns on a 2 m wide reed with 60 threads per inch is

$$2 \times 39.37 \times 60 = 4724$$

Weight in gram of 25 N_e warp yarns having 4% crimp in 1 m length of fabric is

$[4724 \times 1.04] \times [592/25000] = 116.3$ g

Weight in gram of 12 N_e weft yarns having 4% crimp in 1 m length of fabric is

$[2 \times 1.04 \times 40 \times 39.37] \times [592/12000] = 161.6$ g

One meter long fabric would weigh therefore 277.9 g. With a production of 6.858 m/h the amount of fabric produced is

$[6.858 \times 0.2779] = 1.91$ kg/h

4 For a loom running with WIR of 400 m/min and 2 m wide shed, the resultant speed works out to be 200 rpm. Accordingly 1^0 of crank shaft displacement would take [1/1200] s. Hence time allowed for shuttle flight over 150^0 crank displacement is

$[150/1200] = 0.125$s

Time for shuttle flight over 200^0 crank displacement is

$[200/1200] = 0.166$s.

The required shuttle velocity in free flight is

$[(2 + 0.3) / 0.125] = 18.4$ m/s.

The corresponding instantaneous power required for shuttle acceleration over a distance of 0.1m is

$[0.5 \times 0.5 \times (18.4)^2 / \text{Acceleration time}] \times 10^{-3}$ kW.

Time for uniform acceleration of shuttle is

$2 \times 0.1 / 18.4 = 0.01086$ s.

Hence

The instantaneous power required = 7.793 kW.

Maintaining the free flight velocity of shuttle at 18.4 m/s while increasing the time for free flight to 0.166 s would enable the shuttle to travel a distance of 3.05 m which would mean an effective shed width of (3.05 – 0.3) = 2.75 m

5 Power of picking is proportional to $[m. n^3/\theta^2]$, where

m=mass of carrier,

n=loom rpm and

θ=the angular displacement of crank during which carrier passes through shed.

Accordingly under the given conditions

$$[m.\ n_1^3/\theta^2] = [(m/10).\ n_2^3/\ (1.5\theta)^2]$$

Or

$$[n_2\ /n_1]^3 = (10\ x\ 1.5^2) = 22.5$$

Hence

$$[n_2\ /n_1] = 2.823$$

Thus under the changed condition the WIR can go up by 2.823 times.

6 Both conventional shuttle propulsion and gripper propulsion are based on development of strain energy in respective picking mechanisms and its release to the weft carrier. In case of conventional shuttle propulsion the generation of strain energy and its gradual release is simultaneous whereas in the latter the two functions are executed with a phase difference. This fundamental difference in generation and transmission of picking energy in conjunction with a much lower mass is instrumental in much higher value of average acceleration and consequently much higher initial velocity in flight of up to 50 m/s for projectile as compared to a maximum of 15 m/s for a conventional shuttle.

7 Torque generated in the rod is expressed by

$$M_t = K_t.\ \varphi= (\pi.d^4.G).\varphi\ /\ 32.\ell = (E\ .G).\varphi\ /\ \ell$$

Where

E= Polar moment of inertia

G =Shear rigidity

Φ =Angular deformation

And

ℓ= length of rod

If the rod is assumed to be linearly elastic then torque generated would grow proportionately with angular deformation of rod and the plot of torque as function of angular deformation would be a right angled triangle. Area covered by this triangle would represent potential energy stored in the rod and can be expressed as

$$P.E. = [(E\ .G).\varphi\ /\ \ell].\ (\varphi/2) = [(E\ .G)\ /\ \ell].\ [\varphi^2/2]$$

Substituting the values in the equation

$$P.E. = \{[(8163.\ 10^7)\ x\ (5.10^{-9})]/0.72\}x\{0.5^2/2\}\ N.\ m$$

If this entire energy gets converted to kinetic energy of gripper, then

$(1/2). (0.04). (v^2_{max}) = P.E.$

Or

$v_{max} = 59.5$ m/s

The constraints to achieving a high conversion rate of P.E. of torsion rod into K.E. of gripper are inertia and natural frequency of picking lever, inertia of gripper and the dissipating forces such as friction and air resistance.

8 Loom rpm for a 3m width and 1200 m/min WIR is 400.

Hence

Time for one loom cycle is [60/400] s = 0.15 s

Rapier remains in shed for $2/3^{rd}$ of loom cycle which therefore takes 0.1 s

Hence the average velocity of rapier for moving across a 3m shed is 30 m/s

If rapier executes SHM then it enters the shed at 60^0 crank position and leaves shed at 300^0 crank position.

Overall velocity profile of rapier is given by

$s = A \sin \theta$

Where

θ = instantaneous angular position of crank

A = Maximum velocity

Average velocity of rapier during its movement in shed is

$= [3/2\pi] \int A \sin\theta_{[\pi/3 \text{ to } \pi]}$

$= [3/2\pi] [A \cos (\pi/3) – A \cos (\pi)]$

$= [3/2\pi]\ 1.5A = 4.5A/2\pi$

Hence average velocity is 0.72 times the maximum velocity

Hence the maximum velocity is 1.39 times the average velocity

= 1.39 x 30 = 41.7 m/s

Both Dewas and Gabler rapier inserting a single pick would exhibit the same velocity profile.

9 With a tip to tip transfer system the weft is gripped only at its tip, leaving rest of the weft body completely untouched by the carrier. Air and water jets apply drag force on a weft along its entire body while in a loop transfer system a vigorous rubbing takes place between rapier head and weft yarn. A gripper also grips only the tip of weft and does not have any effect on rest of the body of weft. However the impactual shock that a weft is subjected to while getting accelerated as also a possible whiplash effect during braking of gripper subjects the weft to another type of high strain. A similar kind of strain is also subjected by jet streams. Weft tension profile during rapier insertion can however be controlled and maintained at a moderate level as per properties of weft yarn. Thus complex fabrics employing weft yarns of various materials are preferably woven on rapier looms employing tip to tip transfer system.

10 Number of jets controlled by each of the valves 1, 2 and 3 is four, whereas each of the two valves 4 and 5 control two jets. Thus there are in all 16 jets. The loom runs at 600 rpm completing one cycle of operation in 0.1 seconds. Each of the five valves operate over 60^0 of crank shaft rotation which takes (1/60) s. In other words each of the 16 jets blows for (1/60) s accounting for a cumulative blowing time of (4/15) s. Thus air consumption per loom cycle amounts to (400/15) = 26.66 cc.

Just at the point of switching-off of the first valve, a length of 800mm of weft is under action of jets of the first two valves whereas this value drops to 400 mm just beyond this point. This pattern continues till the weft tip reaches 1400 mm reed space at which point the valve 3 is switched off and the valve 5 is switched on. Length of weft under influence of jets of the fourth valve is only 200 mm. This value grows to 400 mm as and when the weft tip reaches 1600 mm reed space. However after 240^0 crank position, this value drops to 200mm again.

11 Each jet covers 100 mm and therefore each valve would cover 200 mm. The weft yarn crosses a distance of 200mm during 7.5 degrees of crankshaft rotation. The first valve has to keep on blowing even after yarn tip has crossed over into the zone of influence of second valve. It can switch off only when the 3rd valve has switched on and yarn tip has crossed 50 mm of the zone under influence of third valve, ensuring that a minimum

length of 250 mm of yarn remains under influence of relay jets. Hence the first valve operates for

$$(7.5 \times 2) + (7.5 / 4) = 15 + 1.875 = 16.875 \text{ degrees of crank shaft rotation.}$$

This would hold true for the next 18 valves. The 20^{th} valve would blow for

$$(7.5+30) = 37.5 \text{ degrees.}$$

Thus the 20 valves would blow for a time equivalent to a total of

$$(19 \times 16.875) + 37.5 = 358.125 \text{ degrees.}$$

For a machine running at 650 rpm, a 1^0 crank rotation takes 2.56×10^{-4} seconds. Hence total blowing time of 20 valves is

$$[2.56 \times 10^{-4} \times 358.125] = 0.0916 \text{ s.}$$

As each valve controls 2 jets and each jet blows 100 cc of air per second, total air blown by relay jets per loom cycle is

$$0.0916 \times 200 = 18.336 \text{ cc.}$$

Over one entire shift the total consumption would be

$$[8 \times 60 \times 0.98 \times 18.336 \times 650 \times 10^{-3}]$$

$$= 5{,}606 \text{ liters} = 5.6 \text{ m}^3 \text{ of air.}$$

12 Considering uniform spacing of relay nozzles, a gap of approximately 72 mm exists between successive nozzles. Each of the first ten valves would thus supply air to a group of four nozzles, each group accounting for about 288 mm of reed space. Hence the lowest value of yarn length under influence of relay jets at any instant would be 288 mm. This statement holds true after the weft tip has gone past the fourth relay jet. As yarn would always be under influence of jets blown by at least one valve and at most by two valves, the upper limit of yarn length under influence of jets would be (288 x 2) = 576 mm.

13 Consumption of air depends on drag force that develops between yarn and air jet. This force is higher for greater yarn surface. A finer yarn and a highly twisted yarn would offer lower surface area to the jet stream than otherwise. Therefore air consumption in both cases would be higher.

14 Consider Figs. 9.12 and 9.13, showing respectively a Venturi tube and a typical sectional view of an air jet nozzle. Assuming laminar flow and implicitly a constant fluid density, the mass of fluid moving through the larger section at a certain rate has to move through the narrower section also at the same rate and hence its velocity in the narrower section must go up. Bernoulli's equation predicts that a rise in velocity would be accompanied by a drop in pressure. By suitably designing the nozzle it is possible to bring down the fluid pressure to sub atmospheric level. This sub atmospheric pressure at the tip of yarn tube creates a suction force which pulls weft from supply package into the jet stream.

15 A jet of air comes out of nozzle at around 85 degrees with its highest velocity and then loses energy over a distance after which its velocity is boosted to a steady value by the relay nozzles. In view of its much higher density and hence higher cohesive force as also substantial drag imposed by inside wall of nozzle, a water jet particle coming out of nozzle exhibits a much lower velocity. After escaping the drag imposed by inside wall of nozzle mouth the water jet particles accelerate rapidly reaching the maximum velocity at about 150 degrees of crank position.

16 Inertia of a gripper as also its dimension are limiting factors to increasing projectile loom rpm while the difficulty in maintaining a sufficiently high air drag on weft over a very long distance limits maximum possible reed width on air jet loom.

Water particles coming out of nozzle exhibit a progressively higher initial velocity over a certain period of the jetting process (Fig. 9. 26). As a result particles coming out earlier are pushed from behind by particles following them. During a very brief laminar zone the jet stream behaves as a continuum but just beyond this zone water particles start forming into individual entities exhibiting their own velocity profiles. As a result of this pushing from behind and overtaking by particles that came out later, the smooth stream assumes the shape of a fist like bump.

Rapier propulsion system is positive in nature as a result of which motion of rapiers can be designed to follow a certain specific function, depending on nature of weft being handled. This aspect is illustrated in Fig. 9.10. The ability to select and impart the most appropriate velocity profile to weft characterizes the essence of rapier propulsion system.

This facility permits insertion of picks of diverse nature during the course of weaving. As no other propulsion system is positive hence rapier system is preferred for weaving fabrics with a wide array of weft yarns.

The rapier heads of Dewas system grip a pick of weft at one point only, somewhat in the manner of a gripper shuttle. They inflict no further physical damage to rest of the inserted pick. On the other hand rapier heads of Gabler system subject weft yarn to vigorous abrasive strain, both during insertion of loop into shed centre as well as during unfolding of loop over the other half of warp shed. Hence the Gabler system is unsuitable for most weft yarns as these yarns are by nature weak and soft.

17 Considering the Table 10.1 it is observed that air jet looms consume highest power (3.2 units) followed by rapier (2.5 units), gripper (1.3 units) and water jet (0.9 units). Air compressor of an air jet loom that supplies air to a large number of jets consumes most of the 3.2 units. Overcoming the inertia and passing through repeated phases of acceleration and deceleration of rapier heads and their driving systems within each cycle of machine operation results in the high power consumption of rapier machines. The inertia of gripper being comparatively less and the fact that it is accelerated once and then decelerated after completing its free flight leads to a much lower power consumption. Indeed the effect of lower mass of gripper is reflected in power consumption which is even lower than that of a shuttle loom. Water jet looms perform best as water, being approximately 1000 times denser than air, applies proportionately higher amount of drag to weft yarn as compared to air stream. This aspect is responsible for superior energy utilization.

In terms of achievable maximum reed width, commercial water jet looms can operate with reed width in the region of 2.5 m while gripper looms and the latest generation air jet looms can weave with about 5.5 m reed width. Monophase rapier looms with reed width of 4m or slightly higher, occupies an intermediate rank. Indeed if WIR is left out of consideration, the gripper technology is eminently suitable for much higher reed width of even up to 12m. Inability of water jet loom to accelerate weft yarn with more than one nozzle, sharp rise in energy consumption of air jet loom with increasing number of relay jets and considerations of high energy and space consumption as also problem of buckling of guiding elements of rapier looms limit values of maximum possible reed width. A free flying gripper on the other hand caries enough kinetic energy to cover very high distance if restriction on flight time is done away with.

All shuttleless looms exercise a degree of continuous control on weft yarn during its insertion. This control comes from the tensioning and braking systems mounted on yarn feeding module. A perusal of Figs. 9.6, 9.10, 9.17, 9.21 and 9.26 helps to develop an understanding of essential differences in nature of variation in weft tension caused by different propulsion systems. Air jet and gripper propulsion systems accelerate weft rapidly from rest and hence there is an impactual shock to yarn before it is accelerated to flight velocity. Subsequently this tension is kept steady over the entire flight. In jet looms repeated and programmed braking of yarn during latter part of its flight decelerates weft yarn while in a griper loom the gripper is gradually brought to a halt by magnetically operated brakes. Such differences in deceleration of weft create differences in their tension profiles. The tension profile of weft carried by rapier is entirely different from those of jet and gripper looms, as has been illustrated in Fig. 9.10 and discussed in detail in section 9.3.2.

18 A modern air jet loom operates with a high WIR and high reed width and can handle a wide range of weft yarns. Supplying clean air at a pressure of 5-6 bars involves relatively simple and inexpensive technology, although it is energy consuming. Sourcing and continuously supplying clean water on the other hand is a complicated matter, limiting widespread use of water jet technology. Moreover water jet looms can process only hydrophobic materials and operate with relatively narrow reeds. The WIR and reed width of rapier looms are limited by inertia of the propulsion system, its displacement function, greater sweep of reed, problem of buckling rigidity of rapier band and larger space requirement. The WIR of gripper loom is limited by the inertia of propulsion system as also by a relatively high sweep of reed.

19 Typical velocity profile of a gripper is provided in Fig. 9.6. A piece of weft dragged by gripper would follow exactly same velocity profile as that of gripper. The velocity profile of a weft yarn dragged by air jet is shown in Fig. 9.21. There are broad similarities

between the two in the sense that in both cases velocity of weft initially picks up from a state of rest to an average value of flight velocity which is broadly maintained till the opposite end of shed is reached, followed by a sharp deceleration to rest. However during flight within shed a weft yarn pulled by gripper exhibits a more uniform profile as opposed to that dragged by air jet stream. This is caused by synchronized switching on and off of numerous relay jets which keep on accelerating the jet stream while the stream itself keeps on dissipating in the surrounding atmosphere while negotiating atmospheric drag. Braking of weft in flight takes place in a modern air jet loom in finite steps while braking of a gripper occurs only after it has safely crossed the entire shed. This aspect also introduces some difference between weft velocity profiles of the two systems.

20 Read answers given to questions 16, 17 and 18 in the foregoing. They underline the reasons for growing commercial popularity of air jet and rapier looms in traditional textile production facilities. However the gripper propulsion system scores over these two in terms of energy consumption, maximum possible reed width and ability to handle with a high degree of reliability a range of high performance fibres such as Glass, Kevlar etc. It may be recalled that only a gripper and a Dewas rapier grip weft by its tip whereby the tip-to-tip transfer in Dewas can prove unreliable with certain kinds of weft yarn. Hence for production of technical textiles a gripper system would be preferred if the economics permits the same.

21 If two spools are mounted on a disc and two yarns coming out of the spools are held rigidly at a point away from the disc and the disc is rotated about an axis joining this point to the disc centre then the two yarns would be twisted around each other moving alternately to the right and to the left of the axis of rotation. If this point is now moved along an arc of 90 degrees such that the line joining this point and disc centre is coplanar with the disc and the axis of rotation is kept unchanged then the rotating disc would still cause twisting of the threads around each other, moving the threads alternately to the left and to the right of line. If this line is parallel to fabric selvedge then the threads would move alternately close to the selvedge and away from the selvedge. In the case of full

rotation of disc one thread would thus always remain closest to the selvedge while the other farthest.

22 Crossing of yarns in leno formed by half rotation of disc occurs once between successive picks while that formed by full rotation occurs twice. Moreover in the full rotation variant one of the crossing yarns always floats below the pick of weft while the other yarn always floats above. The two yarns in a full rotation of disc maintain position about their axis of rotation.

23 Let both looms weave fabrics of P picks/m from same warp and weft.

Let the loom of width R m operate at n rpm such that

$$n. R = WIR = k. R^{0.5}$$

Hence

$$n = k. R^{-0.5}$$

Accordingly the loom of width 2R would operate at rpm

$$k. (2R)^{-0.5} = 0.71n$$

The WIR of loom of width 2R would therefore be equal to

$$2R \times 0.71N = 1.41 n. R$$

This is 1.41 times the WIR of loom of width R. It follows that area of fabric produced by loom of width 2R would be 1.41Z (see Ans. to Q2 in section 2.2) while that produced by one loom of width R would be Z in the same time period.

Cost of a loom of width R is

$$(M+N. R)$$

The cost of one loom of width 2R is

$$(M+2N.R)$$

Hence cost of loom per square meter of fabric produced by loom of width R is

$$R= (M+N. R)/Z$$

While cost for loom of width 2R would be

$$(M+2 N. R)/1.41Z$$

The condition under which it would be more profitable to procure a loom of width 2R would be

$$(M + N.\ R) > 0.71\ (M + 2\ N.\ R)$$

Which leads to the condition that

$$R < 0.71 M/N$$