The Potential of Circular Looms With Regard to Productivity and Cloth Construction

Ziya ÖZEK
Kurt GREENWOOD
Univ. of Manchester, Inst. of Science and Tech. (UMIST) ENGLAND

The next development in the weaving industry to follow on shuttleless weaving may be in multi-phase weaving where more than one shuttle or weft carrier inserts weft simultaneously. The circular loom has been in industrial use for some years now. What tends to be frequently overlooked, however, is that a certain type of multi-phase loom, i.e. the circular loom has been in industrial use for a number of years. The available circular looms are therefore mature machines and with the growing interest in multi-phase weaving generally, it seems reasonable to turn attention to the circular looms with a view to finding out that they can teach us about multi-phase weaving in general and about circular weaving in particular. With this in mind, some research has recently been undertaken at the University of Manchester, Institute of Science and Technology (UMIST) and some of the results of this work are presented here.

In present-day industrial practice, fabrics produced on circular looms are almost invariably woven in the form of hoses for applications where this shape is actually required such as fire-hoses (hoses for fire brigades), bags etc. It is useful to remind ourselves, however, that this need not necessarily be the case. Conventional flat fabrics can be woven on circular looms and this possibility received serious attention by weavers and loom makers some twenty to thirty years ago. It is to some extent related to the possibility of automating circular weaving and is also briefly discussed near the end of this paper.

From the above observations, it will be clear that in approaching the problem of circular looms, one has to distinguish between those aspects of circular looms which are special to them and those which they share with flat multi-phase looms and where they can therefore be regarded as being representative of this type of loom whether flat or circular.

For the experimental work reported here, no special shuttles or weft carriers were used to insert weft concurrently. Instead, a single-phase loom was available and it was decided, therefore, to work on a conventional (single-phase) loom for the purpose of making comparisons. These comparisons were concerned primarily with the maximum cloth density that could be achieved.

1. INTRODUCTION

During the last two or three decades, the weaving industry has taken a large technological step forward by changing from shuttle to shuttleless weaving. From the point of view of industrial application, this change-over is by no means complete and indeed may never be complete because shuttle looms will probably continue to be required for certain types of fabric. However, from the development point of view, the major changes appear to have been realised and many textile engineers and technologists feel that the time has come to look for the next great step forward. It is too early to say when this next step will occur and what form it will take but, up to now, the only technology which appears at all likely to follow on shuttleless weaving is multi-phase weaving where more than one shuttle or weft carrier inserts weft into the warp at the same time. Multi-phase looms have been shown at various machinery exhibitions for some time but so far they have found only very limited application in industry. Therefore, very little practical experience exists with regard to the economic and technical features of these machines.

What tends to be frequently overlooked, however, is that a certain type of multi-phase loom, i.e. the circular loom has been in industrial use for a number of years. The available circular looms are therefore mature machines and with the growing interest in multi-phase weaving generally, it seems reasonable to turn attention to the circular looms with a view to finding out that they can teach us about multi-phase weaving in general and about circular weaving in particular. With this in mind, some research has recently been undertaken at the University of Manchester, Institute of Science and Technology (UMIST) and some of the results of this work are presented here.

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2. THE MAXIMUM CLOTH DENSITY

Experiments to determine the maximum cloth density were carried out on a circular multi-phase loom and on a flat conventional single-phase shuttle loom. The construction on the warp was the same in both looms and the cloth density was varied by changing the pick density and/or the linear density (count) of the weft yarn until the highest possible weft density (as defined below) had been obtained.

2.1 Loom and Yarn Particulars

2.1.1 The Circular Loom

The circular loom used in the experiments was a Fairbairn Lawson Combe Barbour (F.L.C.B.), Mk II, type J2 which was specially designed for weaving Jute cloth in tubular form.

- No. of shuttles: 4
- Weigh of weft package: 0.75 kg
- Weft replenishment: Manual

Diameter of weaving ring: 0.34 m (The function of the weaving ring on the circular loom is similar to that of the breast beam on a flat loom except that the distance from the cloth fell to the weaving ring is much smaller than the distance between the cloth fell and the breast beam).

Cloth circumference: 1.07 m (This is determined by the diameter of the weaving ring).

Cloth well circumference: 1.16 m (This is the length of the weft repeat that can be woven and this aspect has been the subject of a theoretical analysis.

Thus, the paper consists essentially of the following parts:

1. A report on experimental work comparing maximum cloth constructions on single- and multi-phase looms.
2. A theoretical analysis concerning the length of the weft repeat on circular looms.
3. Some observations on the weaving of flat fabrics on circular looms and on automation of the weft supply.

It is hoped that the paper will stimulate interest in multi-phase weaving and also in circular weaving, a branch of weaving which seems to have received little attention in recent years.

2.2 Maximum Cloth Weaving Speed

Maximum loom speed: 130 p.m (thus giving 520 picks/min.)

Actual loom speed: 57 p.m. (228 picks/min.) This was the speed used during the experiments.

Maximum warp insertion rate: 520 x 1.16 = 603 m/min. (Refer to the pick rate the product of picking rate and the cloth well circumference and therefore also an approximate figure).

Maximum warp insertion rate: 228 x 1.16 = 264 m/min.

Shedding motion: 2 cam shafts located at each side of the loom baseplate operate 24 pairs of sectional heald frames situated around the stationary circular reed.

- Shedding sequence: All experiments were carried out with plain weave. For this weave, each pair of heald frames crosses four times in one loom revolution from form alternative sheds for four continuously moving shuttles. The length of the shuttles is such that the space between consecutive shuttles is large enough to accommodate the warp ends from one pair of heald frames. If these pairs would have to stay in the fully open position until the shuttle has left their warp section, this arrangement would not allow any time for shed crossing since a shuttle enters a particular section at the same time as the previous shuttle leaves it. In actual fact, however, the healds can start to change their position well before the shuttle leaves their section so that the shuttle itself keeps the shed open. By the time the shuttle leaves the section, the heald frames are already near the closed-shed position and it is only the warp ends themselves that have to change shed. At any point in time, each of the four shuttles has six pairs of heald frames allocated to it. Of these, four are in the fully open position while the other two are crossing over.

Let-off motion: Negative friction brake type acting on two beams located on either side of the loom.

Take-up motion: Continuous downward take-up with colling up below the working platform.

2.1.2. The Flat Shuttle Loom

A Crompton & Knowles C-5 shuttle loom was used in the experiments. Although it was a 4/1 drop box loom, it was in fact only used for single-colour weaving.

Weft replenishment : Automatic pirn changing

Maximum reed width : 1.10 m

Utilised reed width : 1.005 m

Maximum speed : 160 p.m
Gerçek hızı: 157 ats/dak
Maksimum akı yerleştirmeye hızı: 176 m/dak
Gerçek akı yerleştirmeye hızı: 158 m/dak
Ağızlık açma hareseti: Bezyağıdır üçgen şekline çekilişte kullanılmaktadır ve 20 derece açıktır.
Ağızlık zamanlaması: 255 derece (yüksek akı sıklığı varsa erken ağızlık açı açılır meydana getirir.)
Çubuklar: İğneli rulmanlar
Çözüy birikma hareketi: Negatif
Kumang çekim hareketi: Yırtık dişli tipi

2.3. Çözüy ve Atık
Çözüy sıklığı: Her iki taktada ringde eğrilişli patmuk sıklığı 5x49,2=246 Tex (Ne=12/5)
Kumang çözüy sıklığı: Her iki taktada 8,0 dpi
Atık sıklığı: Dört farklı numarada ringde eğrilişli patmuk sıklığı
Tex: 148 236 295 394
Ne: 4,0 2,5 2,0 1,5
Atık sıklığı: Atık sıklığı (atık orme faktörü) daha sonra açıklanın deneylerin bir bölümü olarak çoğaltılacaktır. Dairesel tezgahların (ve gerçekten tüm çok fazlı tezgahların) önemli dezava-tantalarından birinin çok sık olarak tasarruflan kumaşları dokumakda yeterlilik olduğu düsülmektedir. Dairesel tezgahın, de köttük ağırlığı il-
immiştir. F.L.C.B. dairesel dokuma makinası, bağla-
langıça torbalıkların dokunması için uygun görülen 2,45 ile 6,42 atık/cm atık ağırlığı

2.2.3 Measurement of The Cloth Fall Position
It is well known that the position of the cloth fall during weaving is an indication of the difficulty of weaving a particular fabric. The more difficult it is to achieve the distance between the cloth fall and the weaving ring (or the circular loom) or between the cloth fall and the breast beam (on the flat loom). This change in the cloth fall position not only reduces the shed size, more important still, it leads to "bumping" (a slackening of the fabric during beat-up) and to increasingly unstable weaving conditions until weaving becomes impossible i.e. the limit of weave density is reached. Thus, the position of the cloth fall is one important criterion indicating whether or not the limit of weave density has been reached. For this reason, Measurements of the cloth fall position at various weave densities were carried out on both looms and the results are shown in fig. 1 and 2 for the circular and the flat loom respectively. These diagrams show the progressive movement of the cloth fall away from the weaving area as the weave density is increased.

Fig.1 shows that, on the circular loom, the total change in the cloth fall position amounted to approximately 10 mm, corresponding to an increase in the diameter of the cloth fall of approximately 20 mm, i.e. some 6% of the weaving ring diameter of 340 mm. As far as the flat loom is concerned, the data on the beat-up process which is discussed in the next section, this also is

2.1.4 General Cloth Quality
On the circular loom, the most serious problem concerning cloth quality is to produce uniform warp and weft spacings. With regard to warp spacing, the quality of the fabrics woven on the flat shuttle loom was far better than on those from the circular loom. This is probably due to the fact that the reed on the flat loom places the warp yarn at regular intervals every time it beats up the weft. The stationary reed of the circular loom, however, in contact with the cloth fall and in fact has nothing in common with the flat loom reed except that, like the latter, it guides the warp. Therefore, on the circular loom, the denting of the warp threads in the reed has far less effect on their spacing in the fabric which is also strongly influenced by the uniformity of their tension. Because of the long path of the warp ends between the warp beams and the cloth fall and also because the circular distribution of the warp ends which come from two rectilinear beams gives rise to large differences between the paths of individual ends, spring-loaded compensators are used to balance tension differences. The shuttle drive and the beat-up discs also disturb the warp spacing.

With regard to weft spacing, the differences in warp tension also have an effect because they affect the position of the cloth fall. The method of beat-up which requires the four discs to rotate in the same circular track is also liable to create irregular pickings. As with warp spacing, the weft spacing was also found to be more irregular on the circular loom.

In general, it was noticed that the irregularity of warp and weft spacing increased with finer yarns and at lower pick densities.

2.2 Criteria For Limit of Weft Density
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Yeşilce yazan metin çeviri sonucunda derinleştikten sonra düz tezgah tenge ile ortak hiçbir özellikli sahip değildir. Dolayısıyla ileride tezgah çözüy ipi ve dikişin genelindeki geçici bir önümlü olduğu anlaşılmaktadır. Çözüyün uygulandığı kumaşların kendi üzerine çok etkisi yoktur. Çözüyün çok az etkisi kullanıldığında, dikişin genelindeki geçici bir önumi yoktur. Bu nedenle derinleştikten sonra düz tezgah tenge ile ortak bir önumi yoktur.
bound to have a significant effect on the weft crimp and to a lesser extent on the weft insertion rate as was pointed out earlier.

The changes in the fell position on the flat loom were somewhat larger than those on the circular loom.

2.2.2 The Beat-Up Mechanism On The Circular Loom

The change in the fell position as the weft density is increased is common to both types of loom but the effect of this change on the weaving process is different. The circular loom uses a kind of rotating comb for hoisting up the weft and it was observed that, when the weft density reached a certain value i.e. when the cloth, fell reached a certain position, the fabric would tend to 'jump' over the beat-up comb, thus eliminating the latter's proper function. This phenomenon was studied by means of high-speed cine photography and some stills from the films are shown in figures 3a to 3d. Fig. 3a shows a normal beat-up. Fig. 3b shows the build-up of the cloth fell on the beat up comb. Fig. 3c shows the cloth fell after it has jumped over the beat-up comb and Fig. 3d shows the nature of the beat-up after the 'jump' of the cloth fell.

2.3 The Observed Limits of Pick Density

On the basis of the above measurements and observations, the limits of pick density were found for both looms and these are shown in figures 4 and 5 in the forms of plots of maximum pick density (fig. 4) and maximum weft cover factor (fig. 5) against the linear density (tex) of the weft. Fig. 4 shows that, as expected, the maximum pick density decreases as the weft linear density increases. The results shown in fig. 5, however, could not be predicted. They indicate that the maximum weft cover factor increases as the weft linear density increases.

3. THE LENGTH OF THE WEAVE REPEAT IN CIRCULAR LOOMS

This problem was the subject of a published exchange of opinions in the years 1962/3 when Townsend presented a paper to the annual conference of the Textile Institute outlining the capabilities and limitations of circular looms. Commenting on this paper, Ineson pointed to the relationship between the number of shuttles and the length of the weft repeat in terms of the number of picks and stated (mistakenly) that number of shuttles must be equal to or a multiple of the number of picks in the weft repeat. Although the comment was incorrect, it had the fortunate result of inducing Townsend and his
güçli mekanizmaları. Bunun bir sonucu olarak ilacindaki incelenen vurus işlemi üzerindeki etkisi altında atık kvm̄i üzerinde ve daha az ölçüde, daha önce belirtildiği gibi, atık yerleştirme hızı üzerinde de önemli etkileri olduğunu görmüş olmalıdır.

2.2.3. Dairesel Tegahda Vurus Mekanizması


2.3. Atık Sıkılığının Gözlemelenen Sınırlar

Yukarıdaki gözlemcilere ve gözlemcileri göre her iki tezgah için de atık sıkıştırma belirtir, nedeni bu eylemin, mekik yayının bir eriştiğini, raporunun atık sayısı olarak uznulugu arasındaki bağlamıyla iyi etti ve mekik yayının vurusu yapmakta olup atık eşiğindeki uznulugu daha olsa kalmış gibi görünüyor. Fig. 4. Effect of weft linear density on maximum pick density.

Şekil 4. Atık kumaşın çözügizinin vurus çalışmasının ortak etkisi.

3. DAIRESEL TEGAHLARDA ORÇU RAPORUNUN UZUNLUĞU

Bu problem, Townsend 1962-63'teki Tezgahın Entellitü'nün yilık konferansında dairesel tezgahların yeteneklerini ve sınırlarlarını özetleyen bir teşkilat tarafından yapılan yayınlananmış bir görüş alıcılarının konusu idi. Bu teşkilat üzerinde görülen belirtildiği üzere, birer dilimliden iner, mekik yayının bir eriştiğini, raporunun atık sayısı olarak uznulugu arasındaki bağlamıyla iyi etti ve mekik yayının vurusu yapan atık eşiğindeki uznulugu daha olsa kalmış gibi görünüyor. Fig. 5. Effect of weft linear density on maximum weft cover factor.

Şekil 5. Atık lineer yoğunluğunun maksimum atık eriştiğini göstermektedir. Bu raporunun atık eşiğinin, mekik yayının eriştiğini göstermektedir. Fig. 6. Circular loom with 4 shuttles weaving 2/1 twill (One chage line).

Şekil 6. 2/1 Dilim dokuyan 4 mekikli dairesel tezgah (Tek değişşim çizgisi).
colleagues to consider in greater detail what the true position was. Their findings were summarised by Townsend and the salient points of this analysis will be quoted here very briefly but with some additions which are intended to further clarify the situation. Fig. 6 is a modified version of a diagram produced by Townsend and any reader who is seriously interested in the subject would be well advised to study the original paper.

Fig.6 represents a loom with four shuttles (S.T.U.V) at a particular moment in time. The fabric is a 2/1 twill, i.e. a weave which has a pick repeat of 3. This means that the conditions stipulated by Ineson are not fulfilled because the number of shuttles is neither equal to the weave repeat nor a multiple of it. Townsend, however, demonstrated with the aid of fig.6 that the fabric could nevertheless be woven. One of the present authors has shown that the shedding motion of any multi-phase loom, whether flat or circular, must be divided into a much greater number of sections than there are shuttles inserting weft simultaneously, (In the F.L.C.B. loom, for instance, the number of shuttles was 4 and the shedding motion was divided into 24 sections) For simplicity, however, the shedding motion in fig.6 is only divided into four sections (J, K, L, M). With regard to the weave repeat, the 2/1 twill has three different sheds (i.e. shafts I + II, I+ III and II+ III lifted) These different sheds required by the weave may or may not be disrupted, depending on the draft, and the same applies if the shuttle changes into a different shed. This becomes clear from figures 7 and 8. Fig.7 depicts the situation in a section of the weave where the shuttles do not change into a different shed. Here, uninterrupted continuation of the straight draft across the section boundary ensures that the sheds in any one section of the warp alone. Here, the same shed exists when the same combination of heald shafts is lifted.

When one considers, however, the situation where a shuttle or a weft thread passes from one section to the next, question a), in theory at least, can, in practice, be answered in several different ways because one of the present authors has shown that the continuity of the weave in the weft direction when the picks passes from one section to the next depends not only on the shed sequence but also on the direction of movement of the shuttles. Following now the arrows shown in fig.6, the following change is necessary in order to preserve the shedding motion in different sheds as it passes the line OA which will be referred to as a "change line" This is necessary, first of all, to clarify:

Question a) can be answered quite unambiguously when one considers the sheds in any one section of the weave along any one weft thread (which is equally important) from one shed to another. This question arises from the fact that normally the continuity of the weave on any one pick is preserved by the shuttle staying in the same shed. In order to answer this question, it is necessary, first of all, to clarify:

a) What is meant by "the same shed"?
b) Must the shuttle always stay in the same shed in order to ensure continuity of the weave in the weft direction?

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weave continuity. If the continuity of the draft were interrupted here, the weave would also be disrupted. Fig. 8 shows the draft arrangement at a section boundary which is a change line. Here, an interruption of the straight draft combined with a shed change leads to weave continuity. Indeed, if the shuttles here remained in the same shed, the continuity of the weave would be interrupted.

The lower parts of figures 7 and 8 can be interpreted as fabric-cross-sections but also as indicating the shuttle path in the vicinity of a section boundary. At a boundary which is not a change line, the sequence of shuttle passages will be as follows:

Shuttle passes  S T U V S T U V From Shed 1 2 3 1 2 3 1 To Shed 1 2 3 1 2 3 1

In this light of the table, the three cross-sections will be regarded as showing the three consecutive passages of a single shuttle as it crosses the same boundary. The sequence of these passages is the same for all shuttles but their start is different. Thus, an observer, looking at a particular boundary at the moment in time when shuttle S passes from shed 1 to shed 2 (as in figure 7), will observe shuttle U while it passes from shed 2 to shed 2.

For fig. 8, the above kind of table looks very similar except that at a boundary which is also a change line, the next higher shed number.

Most practical weavers would regard the draft shown in fig. 7 as the normal state of affairs and would describe the change-over to fig. 8 as "casting some ends out." Townsend and colleagues did not discuss this change-over in these terms and showed how by appropriate casting out of ends at the change line it is perfectly possible to weave a 2/1 twill on a circular loom with four shuttles inspite of the fact that this required the shuttle to change sheds at some stage.

A rather unexpected outcome of his analysis was the fact that, although there are four section boundaries, each shuttle changed shed at only one of these boundaries and that the change line was the same for all shuttles. At first sight, this state of affairs would have been better described as an arbitrary choice of change lines. Indeed, three shuttles could have been described as having arbitrary choice of change lines that are common to all shuttles. But this would require that the change lines be specified in the same way for all shuttles. Townsend clearly attempted to have things as "normal" as they could be under the circumstances. As Fig. 6 shows, he placed shuttle S in shed 1, shuttle T in shed 2 and shuttle U in shed 3. However only three different sheds available to accommodate four shuttles, he then had to place shuttle V in the shed indicated by an asterisk. If this condition of the four shuttles over the three sheds remained unchanged as the shuttles travel round the loom, a shed sequence 1, 2, 3, 1, 2, 3 etc. would occur in every one of the four sections and this would disrupt the warways continuity of the 2/1 twill which requires that the change line is in the same section as V.

From this, it follows that, at the section boundary where the shedding sequence of the shuttles is wrong, i.e. where a shuttle in shed 1 is followed by another shuttle in shed 2 instead of a shuttle in shed 2, the sequence of shuttle passages in this case shuttle S must change into shed 2 as it crosses the section boundary OA. As a result of this change and of the movement of the shuttles, shuttle S is now in section K and in shed 2 while shuttle T is in section I and (not having changed shed) is also in section I so it is now shuttles S and T must change sheds (into shed 3) but the change takes place at the same section boundary as before. It can easily be shown that the same applies to all three shuttles and it explains:

Firstly how the choice of the initial shuttle and shed distribution determines the position of the change line and secondly why the change line remains stationary inspite of the rotation of the shuttles and of the shed.

All the above argument is essentially due to Townsend and colleagues. They did not point out, however, that their choice of starting conditions was arbitrary. One of these alternatives is to start off with all four shuttles in the same shed (say shed 1) in this case which is illustrated in Fig. 9 the shed sequence of consecutive shuttles would be wrong at every change line and therefore all four boundaries would have to be change lines. This arrangement has a certain attraction because it preserves the basic symmetry of the system. There is no arbitrary discrimination between individual section boundaries and all shuttles would always be in the same shed.

In choosing his particular starting position, Townsend clearly attempted to have things as "normal" as they could be under the circumstances. As Fig. 6 shows, he placed shuttle S in shed 1, shuttle T in shed 2 and shuttle U in shed 3. Having only three different sheds available to accommodate four shuttles, he then had to place shuttle V in the shed indicated by an asterisk. If this condition of the four shuttles over the three sheds remained unchanged as the shuttles travel round the loom, a shed sequence 1, 2, 3, 1, 2, 3 etc. would occur in every one of the four sections and this would disrupt the warways continuity of the 2/1 twill which requires that the change line is in the same section as V.

From this, it follows that, at the section boundary where the shedding sequence of the shuttles is wrong, i.e. where a shuttle in shed 1 is followed by another shuttle in shed 2 instead of a shuttle in shed 2, the sequence of shuttle passages in this case shuttle S must change into shed 2 as it crosses the section boundary OA. As a result of this change and of the movement of the shuttles, shuttle S is now in section K and in shed 2 while shuttle T is in section I and (not having changed shed) is also in section I so it is now shuttles S and T must change sheds (into shed 3) but the change takes place at the same section boundary as before. It can easily be shown that the same applies to all three shuttles and it explains:

Firstly how the choice of the initial shuttle and shed distribution determines the position of the change line and secondly why the change line remains stationary inspite of the rotation of the shuttles and of the shed.

All the above argument is essentially due to Townsend and colleagues. They did not point out, however, that their choice of starting conditions was arbitrary. One of these alternatives is to start off with all four shuttles in the same shed (say shed 1) in this case which is illustrated in Fig. 9 the shed sequence of consecutive shuttles would be wrong at every change line and therefore all four boundaries would have to be change lines. This arrangement has a certain attraction because it preserves the basic symmetry of the system. There is no arbitrary discrimination between individual section boundaries and all shuttles would always be in the same shed.

Having demonstrated that a circular loom with four shuttles can produce a 3-pick weave repeat, it remains to examine the warway continuity of the same loom a weave repeat which is larger than four. This problem can be studied in relation to, for instance, a 5-end weft face satin whose 5 shafts form 5 different sheds as follows:

Shuttle passes  S T U V S T U V From Shed 1 2 3 1 2 3 1 To Shed 1 2 3 1 2 3 1

propagation and the propagation of waves. The propagation of waves in a medium is determined by the frequency of the waves, the speed of the medium, and the nature of the medium. In a vacuum, the speed of light is a constant value, whereas in a medium with a higher refractive index, the speed of light is slower. This is because light travels slower in a medium with a higher refractive index due to the interaction between the light wave and the medium's particles. The speed of light in different media is given by the equation:

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\[ v = \frac{c}{n} \]

where \( v \) is the speed of light in the medium, \( c \) is the speed of light in a vacuum, and \( n \) is the refractive index of the medium. The refractive index of a medium depends on the type of medium and can be measured using optical instruments. For example, the speed of light in water is 22 cm/s, while in air, it is 300,000 cm/s. The refractive index of water is 1.33, which is higher than that of air, which is 1.00. Therefore, light travels slower in water, which is why light bends when it passes from air to water. This phenomenon is known as refraction.

In summary, the speed of light in different media is determined by their refractive indices and is given by the equation \( v = \frac{c}{n} \). This equation shows the relationship between the speed of light in a medium and the refractive index of that medium. The refractive index is a measure of the light's interaction with the medium, and it indicates how much the light is slowed down compared to its speed in a vacuum.
neither an upper nor a lower limit to the size of the concluded that the number of shuttles represents we&im concern the number of ends that have to be cast out to weave, the only questions that need to be answered change lines).

out is equal to the number of ends one has to move same way and their individual interlacings are bearing in mind that, at a change line, the shuttle change lines). Weaves where all warp ends interlace in the same way and weft is slightly less than 400 shuttles weaving 4 ends at the other three. In the former case, the total number of ends 402 and in the latter case 397. Both figures are probably sufficiently near the target of 400 to be acceptable.

1. THE WEAVING OF FLAT FABRICS ON CIRCULAR LOOMS

It is of course always possible to cut a hose lengthways and thereby convert it into a flat fabric. The binding or sealing of the selvedge created by this method should not present any problems. Nor should the spirality of the weft which would not be different from the situation encountered in flat multi-phase looms where the angle between warp and weft is slightly less than 90 degrees. A more fundamental problem concerns the automation of the weft supply which presents no serious problems in flat looms, but which is very difficult if not impossible in circular looms. It must be remembered, however, if this difficulty arises from the fact that, at present, circular looms are invariably used for weaving hose where the shuttles never leave the warp shed and therefore remain inaccessible while the loom is running. On such looms, the weft replenishment is only semi-automatic (as was the case on the F.L.C.B. loom). When a weft package is nearly exhausted, a photo-electric sensor ensures that the loom is stopped and the shed is levelled so
as to make the shuttle temporarily accessible for the manual insertion of a new weft package. This latter operation could probably also be done automatically but it would require a rather intricate mechanism and would still involve stopping the loom since the shed must be levelled. For these reasons, designers of circular looms have so far refined from introducing fully automatic weft replenishment. The situation would be different, however, if circular looms were used for the weaving of flat fabrics. For this kind of weaving, it is not necessary for the warp to enclose a complete circle and therefore a gap can be introduced into the warp between the two selvedges. As the weaving, it is not necessary for the warp to enclose a complete circle and therefore a gap can be introduced into the warp between the two selvedges. As the weaving progresses, the weft can be replenished through this gap, it becomes temporarily accessible for weft replenishment.

With regard to the weft cover factor which provides in practice the only means of comparing the weft densities of fabrics with different counts of weft yarn, it was found that the maximum value that could be woven increased as the linear density (tex value) of the weft increased.

With regard to weave, theoretical considerations of earlier workers, amplified by the present authors, indicate that the versatility of circular looms is considerably greater than is widely believed or used in practice. This could be of importance if the idea of weaving flat fabrics on circular looms were to be seriously considered again. This idea would also open up the possibility of introducing fully automatic weft replenishment on circular looms.

The present paper deals only with limited aspects of circular and multi-phase weaving. The work reported here, however, has shown that further researches in this field may well be

5. CONCLUSIONS

The work reported here has drawn attention to the essential similarity between circular and flat multi-phase looms, particularly with regard to the method of beat-up which differs in principle from the method used on conventional single-phase looms. This difference probably accounts for the fact that, with the same warp and weft, significantly higher weft densities could be achieved on the flat single-phase loom than on the circular loom. The criteria used to establish whether the maximum weft density had been reached, i.e. excessive bumping on the single-phase loom and "jumping" over the beat-up reed on the circular multi-phase loom appeared to be appropriate for this purpose.

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