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10 HOW THE STRING MOVES WHEN BOWED

10.1 INTUITION OR KNOWLEDGE?

The physical relationship between the bow and the string has been given scant attention by most players. Very little has been written about it outside scientific circles and most musicians usually form rather sketchy metaphysical impressions about how their instrument works mechanically.

An observant player will discover intuitively that when alternating between two notes an octave apart, the bow must travel almost twice as fast for the higher note than for the lower, in order to achieve equal tone and volume. The less observant player will play both notes with the same bow speed, making at least one of them sound unsatisfactory; the upper note is often constricted or the lower one wooly.

Speaking in physics, there is a proportional relationship between the frequency (pitch) of a note, and optimum bow speed, assuming constant pressure. As the frequency of the higher octave is twice that of the lower, it is in fact necessary for bow speed to be twice as fast on the upper note.

10.2 WAVE FORMS IN THE STRING

It is helpful to see how wave forms move in a vibrating string. 10.2(i) shows a string at rest. Look at fig. 10.2(ii) **a**, which represents a completely flexible string stretched between two fixed points, and drawn upwards in the middle. The moment it is released (as in pizzicato) the 'angle' (wavetop) in the middle will move outwards in both directions along the string, at a speed which is determined by the mass of the string per unit of length, and the tension in the string.

In **b**, the wavetops have nearly reached fixed points at either end. The string is exerting a constant force upwards on each of these points.

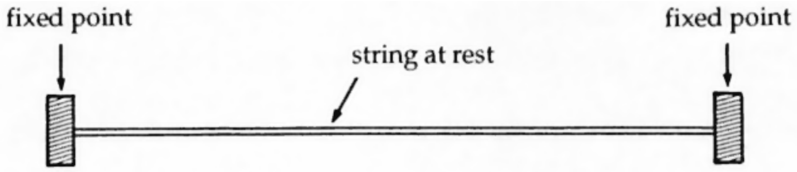

Fig. 10.2(i)

In **c** the wavetops have just reached the attachment points and start moving them downwards. We imagine this movement to be so small that its influence on the string is not visible. (But even two concrete walls would be microscopically moved by a string in this way.)

In **d**, the wavetops have moved down to the underside of the string, where they continue their progress with the same speed as before. The wavetops are, however, slightly reduced in size, as some of the energy will have been transferred to the material to which the string is attached. On an instrument, the energy which goes into the bridge will be futher transmitted to the belly, the bass bar, the sound-post and the back, and so set the air in motion both inside and outside the body of the instrument. Most of the energy is nevertheless retained in the string, and the wavetops continue their circular tours in two opposing directions.

In **e** the wavetops meet at a point on the underneath of the string, but this happens without any transfer of energy, or influence on one another, and so they continue via **f** to **g**, where the attachment points of the string are this time forced a little upwards, exactly the reverse as at **c.**

Fig. **h** shows how the wavetops once more arrive on the upper side of the string, and in **i** they meet once more and give the string a form which is very similar to the initial position (fig. **a**). The slight difference in height (amplitude) between **a** and **i** is due to the small fraction of energy that left the string and was transmitted to the fixed points at each end. The string has now gone through a whole cycle of vibration, and the time it has taken to do this is called a **period.** If left unaffected by outer influences, it will continue to vibrate in the same manner until all energy has left it, the wavetops becoming gradually lower and lower.

It should not be difficult to appreciate that if the string had been shortened by moving the fixed points nearer one another, the time taken for one period (i.e. the time the wavetops need to complete a whole cycle) would have been proportionately shorter, because the wavetops would have had a proportionately shorter distance to travel. This assumes constant tension and constant mass per unit of length of the string, so that the wavetops travel at the same speed as originally.

A shorter time per period will mean more periods per second – higher frequency (= periods/sec.), i.e. a higher note. If the length of the string is halved, the wavetops will only have half as far to go, thus doubling the frequency – a rise in pitch of an octave. Every player knows that an octave can be located exactly half way up the instrument!

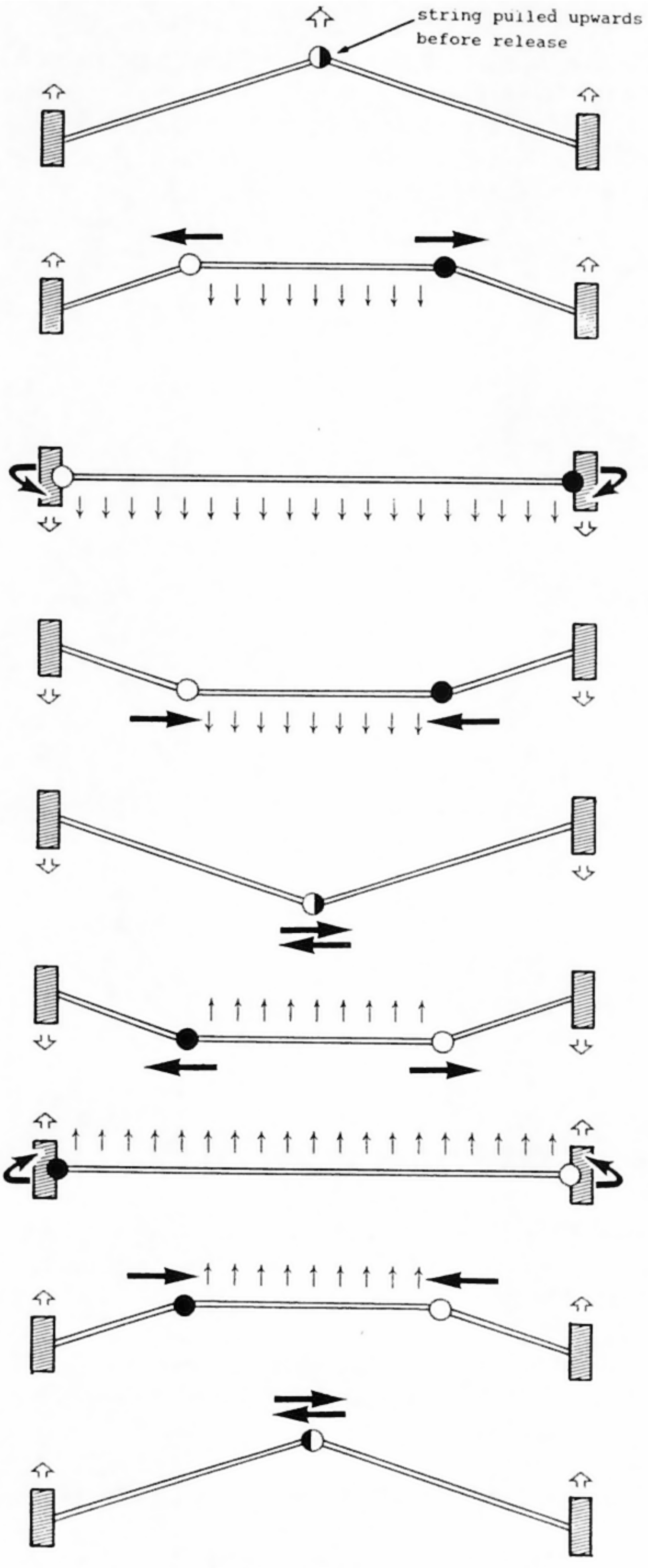

Fig. 10.2(ii)

No string being perfectly flexible, when the bow is drawn nearer to one of the attatchment points (bridge), the wavetops will, with decreasing sharpness, describe a path similar to the dotted line in fig.10.2(iii). This curve is familiar and can be seen in the string while it is being played, leading to the belief that it swings from side to side in this shape. In reality the form is much more angular: the waves travel along the string, and not across it. The wave speed on the G string is ca.400 m.p.h.!

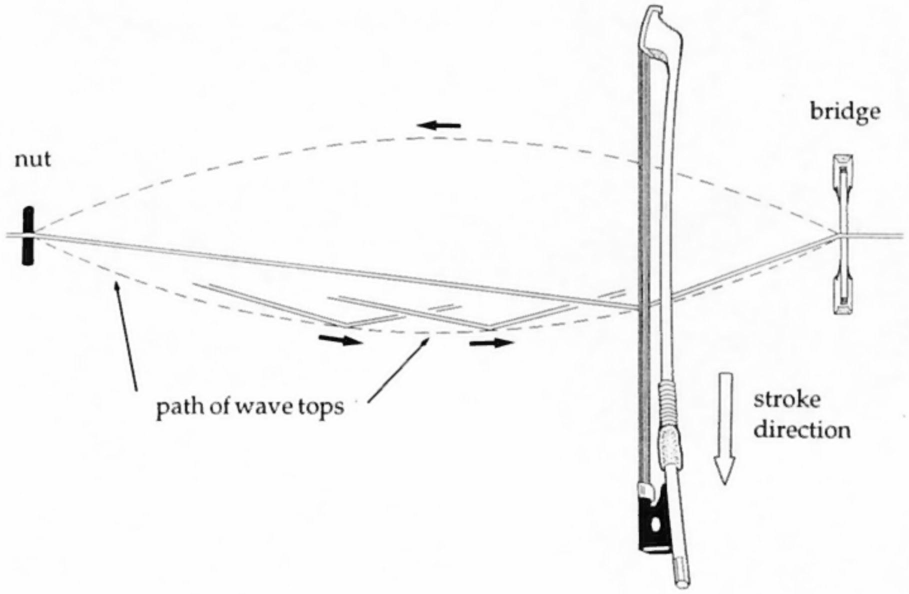

Fig. 10.2(iii)

10.3 THE BOW'S CONTACT WITH THE STRING

Before discussing the influence of the bow on the string it is necessary to understand a little about friction, and to clarify the nature of the contact between bow and string at different points in the vibratory period.

When a bow is drawn across a string, there are two different forms of friction to be considered. They will both occur at different times at the point of contact (the contact surface).

– **sliding friction,** or the resistance between two bodies which are in motion against each other.

– **static friction,** or the resistance between two bodies which are at rest with each other.

The sliding friction between two bodies is approximately proportional to the force which they exert on each other. On the other hand the size of the contact surface makes no difference.

The static friction is at any time equal to the force which attempts to move the one body in relation to the other, in a direction parallel to the plane of contact between them. This is valid as long as the two bodies are at rest with each other.

Maximum potential static friction between two bodies is generally greater than the sliding friction between them, but in the same way as with sliding friction, it is also approximately proportional to the force the two bodies exert on each other, and is independent of the size of the contact surface.

The following experiments will help to reach an understanding of the difference between static and sliding friction. Fig.10.3(i) shows a wooden block resting on a table. A cord is attached to the block, and the other end of the cord is connected to a 2 inch long spiral spring. The other end of the spring is screwed to a scale rule so that the extension of the spring can be read off at any time when the ruler is pulled away from the block.

Experiment No.1
First, it must be determined how far the spiral spring can be pulled out before the wooden block begins to slide. This will give an indication of how much static frictional resistance can be obtained. It is found that the block begins to slide every time the spring reaches 4 inches. At this moment the pulling force is greater than the maximum static friction.

Experiment No.2
The pressure of the block on the table (and thus, also, the pressure of the table on the block!) is increased by placing another, slightly smaller block on top of the original one. Experiment 1 is repeated. There is now more pressure on the table. This time, the spring can reach an extension of 5 inches before the blocks begin to slide. This shows quite clearly that the static friction can be increased when the weight on the table is greater.

Experiment No.3
Starting again with only one block, as in experiment No.1, this time the block is given a little push, so that the sliding movement over the table has already started when the length of the spring is read off. This length turns out to be about 3 inches, as long as the block is kept sliding by pulling on the ruler.

So the sliding friction is less than the maximum static friction. (This agrees with the practical experience of walking on ice, or up hill, when the ground is slippery.) The speed with which the ruler is pulled makes no difference to the result; the spring reaches the same extension each time.

Experiment No.4
If the last experiment is repeated, but with the smaller block on top of the original one (i.e. with increased weight on the table), it is found that the sliding friction, also, increases with increased pressure (opposing forces) between the bodies. It is found that the spring this time reaches a length of about 4 inches.

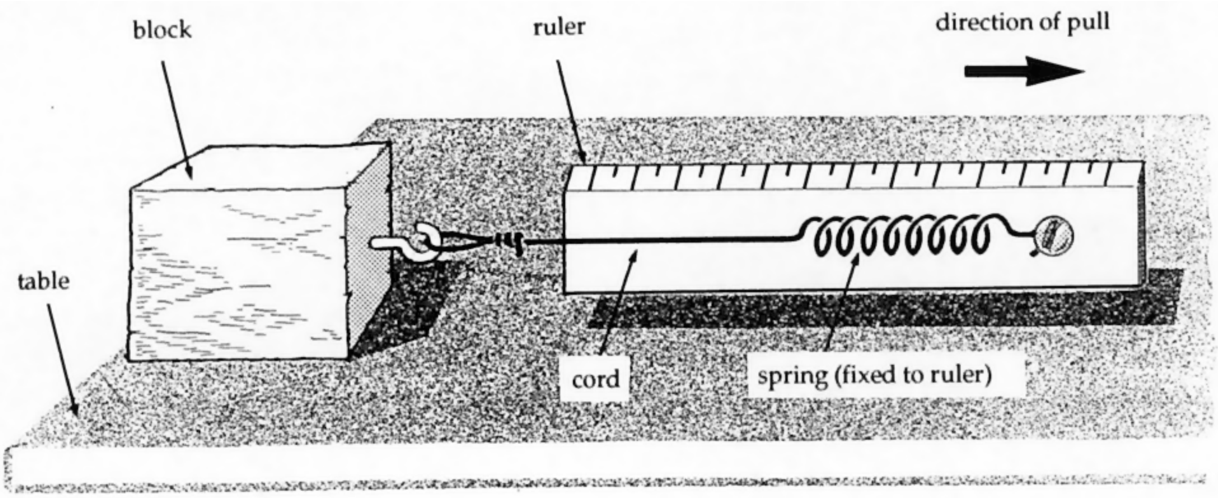

Fig. 10.3(i): Apparatus for Experiment Nos. 1–4.

This is rather interesting, because if the spring is pulled out to a length of about 4 inches, it can be done **either** with sliding friction and increased weight (both blocks) **or** with (the same amount of) static friction, **in which case** not quite so much weight is required on the frictional surface between the block and the table (one block is enough). It will be shown how these findings have a direct bearing on the bowed string.

To continue with some new experiments (see fig.10.3(ii)), a string is stretched between two fixed points, and a bow is set up which can be drawn at a constant speed, and with a constant pressure (e.g. by means of a motor).

Experiment No.5

The bow is placed on the string, and the pressure adjusted to a certain value, so that the initial friction will be static. (The bow does not move across the string.) The bow is then set in motion, lengthwise, and the string accompanies it sideways until the maximum static friction is attained, at which moment the bow hair loses its hold on the string.

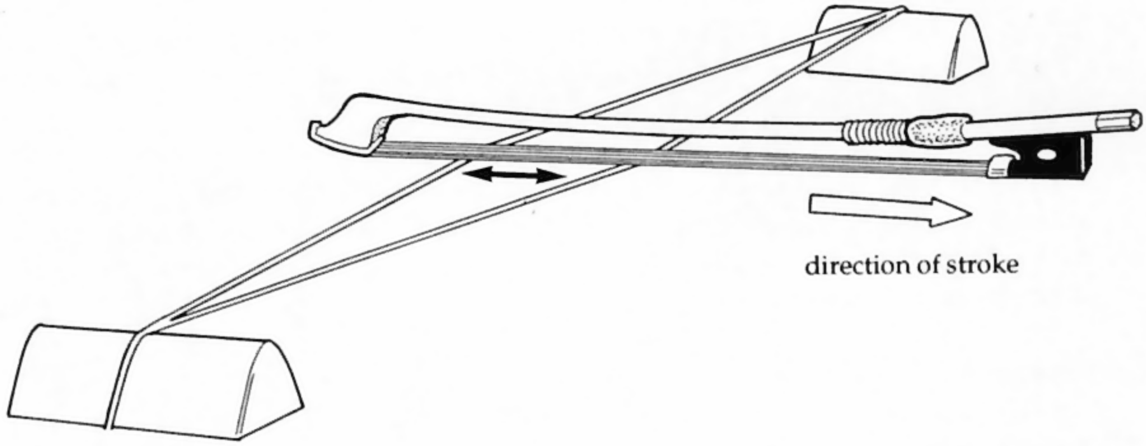

Fig. 10.3(ii): Experiment No.5.

The frictional resistance is now suddenly reduced, because the form of friction has passed from static to sliding. (The pressure of the bow on the string is kept constant the whole time.) On account of its tension, the string 'rebounds' rather quickly towards the imaginary straight line between the fixed attachment points.

At the moment this happens, a wave motion is produced in the string (with two wavetops), as illustrated in fig.10.2(ii).

As the middle of the string – or the point of contact with the bow – moves from the side to which it was first pulled, towards the other side, the horizontal force between the bow hair and the string is reduced. At one particular moment this is so little in comparison with the vertical force (weight) of the bow, that the friction suddenly becomes static once more, and the string again follows the bow hair sideways, just as if they were glued together. This occurs at the moment when the horizontal force between bow hair and string has become less than the sliding friction caused by the pressure of the bow, which in practice normally happens at the moment when one of the wavetops travels past the bow hair on the opposite side of the string, after being 'reflected' by the bridge. (The value of the sliding friction is equal to the product of the bow's force on the string and a sliding friction factor, which is determined by the nature of the two materials which are rubbing against each other.)

If this last phenomenon is compared with the earlier experiments with the blocks, we shall have to imagine that in experiment No.3 part of the tension in the spring was suddenly lost, so that this instantly retracted to less than 3 inches. The block would then stop moving, because the force of the cord would no longer be great enough to keep it moving (the pulling force being less that the force of sliding friction). If the ruler continued to be pulled, the block would remain in on place (with static friction) until the length of the spring reached 4 inches, as in experiment No.1. The block would then begin to slide, and the spring would after a little while again return to an extension of 3 inches.

One of the reasons for using resin on the hair of the bow is that it increases the difference between static and sliding friction.

Experiment No.6

The experiment is repeated, but this time the bow is not set in motion with the hair pressed against the string. The bow begins in the air above the string, and is set in motion lengthwise. It is lowered slowly towards the string **until the bow pressure used in experiment No.5 is attained.**

What happens now? Since the bow is already in motion, relative to the string, while it is in the air, sliding friction is produced from the very first moment of contact. (This type of friction, as we know, is less than the static friction can be.) As the bow pressure increases, the friction of motion increases, and this means that the string is drawn further and further out to the side.

But, since only sliding friction has been produced, the string will never be drawn aside as far as was the case with static friction – and what is worse: **if the friction was completely even along the hair, the string would have remained at rest when it reached the point where the tension of the string was in balance with the frictional force!** So there would be no recoil to set waves in motion.

In practice, the situation is not **quite** so bad, because the friction will never be perfectly even at all points on the hair, so that a series of slight recoils in the string occur close behind each other – and each of these will start waves, which all pursue their paths round the string, one after the other – and the result will be an indeterminate sound, reminiscent of ponticello or a harmonic.

And so the most important point is reached:

In order to attain a distinct, fundamental and pure sound, it is absolutely essential that the bow hair only loses its grip on the string **once** in the course of each vibrational **period** (i.e. only once in the course of the time it takes for a wavetop to pursue its path round the whole of the free length of string which is in vibration). This can be attained only by a periodical alternation between static and sliding friction. IN PRACTICE THIS MEANS THAT SUFFICIENT PRESSURE MUST BE ESTABLISHED **BEFORE** THE BOW STARTS TO MOVE LENGTHWISE. It is **essential** to start with static friction. (See also 2.2).

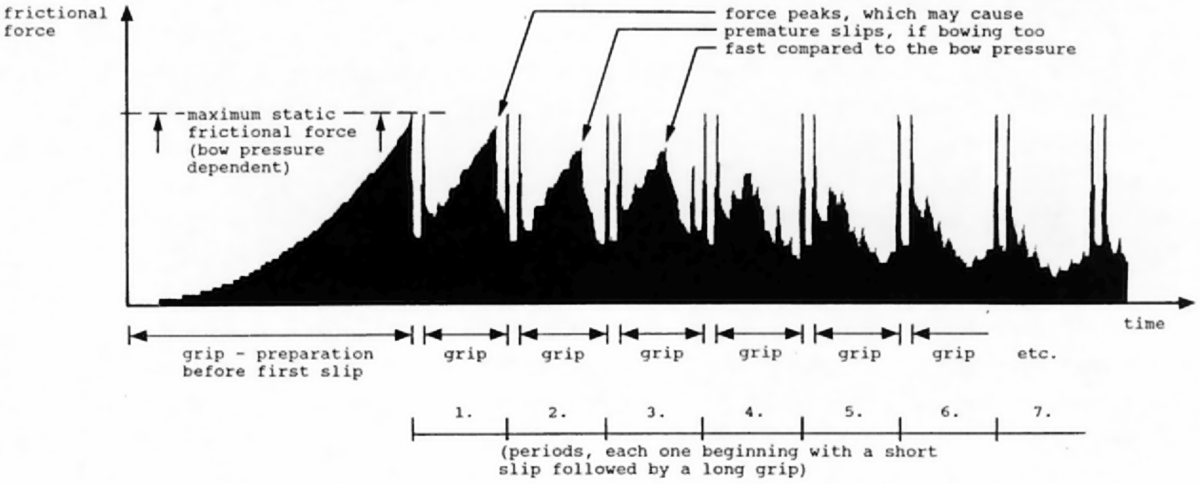

Fig. 10.3(iii)

What is required is that the bow should catch the string and draw it out to one side **once** in each period. This is in many ways similar to giving the string a pizzicato impulse each time the wavetops return from their circuits round the string. But, as will be remembered from the section dealing with the movements of the string, the wave forms return with almost undiminished strength (only a little of the energy has been transmitted to the bridge, etc.), and the 'pizzicato impulses' after the initial one do not need, individually, to contribute more energy than that which has left the string.

This is very important, as it means that THE STRING IS SUPPLIED WITH MOST ENERGY BY THE BOW AT THE VERY BEGINNING OF THE NOTE.

See fig. 10.3(iii), showing the (computed) frictional force between bow and string during the seven first periods of a note. This force is the source of energy to the string.

Every time the maximum static frictional force is exceeded, sliding friction occurs, and the force immediately takes a lower value until static friction happens again. Notice that the frictional force makes very high peaks during the static part of the first periods. These are a threat to the clear note, because they can – if the bow moves too quickly – rise too high and cause premature slips, resulting in a flageolett-like or scratchy sound. While these peaks are a function of bow velocity, the maximum frictional force is a function of bow pressure.

After a few (good) periods the danger of scratching is greatly reduced, since the frictional forces and the required energy transference between bow and string become much less during the sticking part of the periods: 'the string becomes more tolerant to the stroke', allowing for greater variance and tone colouring.

Notice also that the energy put into the string before the first slip, does not give rise to any significant wave motion in the string (i.e. it is inaudible), and therefore can occupy any length of time, regardless of the string's vibratory period. In other words, the bow can be placed on the string, and the string drawn out to the side, well before it is to release the bowhair for the first time, at which moment the wavetops begin their circuits, with the resulting sound from the instrument.

10.4 BOW SPEED

If the contents of 10.2 and 10.3 have been digested, it can easily be appreciated that bow speed and pressure have a highly critical influence on the string. If, while doing experiment No.5 (section 10.3), the distance the string followed the bow hair out sideways had been measured (or rather, how far the string slipped back every time it lost its grip on the bow hair) it would have been possible to calculate the correct relationship between frequency (i.e. pitch) and bow speed.

For example, suppose the string were to be drawn with the bow, until it was unable to continue; it loses its grip, and slides back 2mm before the bow hair once more gets hold of it and brings it back to approximately the same point - etc.

This can be illustrated as in fig. 10.4. The sawtooth line shows how the string accompanies the bow for most of the time - without slipping on the hair. The steeper parts of the line show where the string slips and recoils quickly, until the hair once again gets hold of it. (It was demonstrated a long time ago, by means of photography with a moving film through a slit, and later with more modern methods, that this is what really takes place during playing.)

If wave forms in the string have a period of 1/100 second, the natural frequency of the string will be 100 cycles per second (= 100Hz ≈ GG, which in double bass music is written G).

To synchronise bow grip with recurrent wave forms, the bow must lose its grip exactly 100 times per second. Each recoil of the string is, as will be remembered, 2mm. This determines that bow speed should be (if ignoring the bow's movement during slip):

$$\frac{2\text{mm} \times 100}{\text{sec}} = 20\text{cm / sec}$$

Too little bow speed leads to the wave forms being impeded (damped) by the bow hair. Because the waves return 'too soon' to the initial point on the string, the sound will be 'strangled' and the frequency (pitch) will fall slightly.

Too much bow speed causes more than one recoil per period, because the bow cannot, with the same pressure, draw the string more than 2mm out sideways each time! (See 10.5)

If in the example above, a bow speed of 30cm / sec had been used, the string would, naturally enough, have made

$$\frac{30\text{cm / sec}}{2\text{mm per recoil}} = 150 \text{ recoils per second}$$

or 1.5 recoils per period.

In reality there will be at least two recoils per period, because the bow moves 3mm in the course of the very first period, thereby producing (at least) **two** recoils in the string. Each of these will form wavetops, which begin their circuits in the usual way (**after each other** along the string, round to the other side, and back again). The bow hair gets hold of **both** when they return, and provides them both with new energy, so that the pattern set in the first period will be maintained in all the subsequent ones.

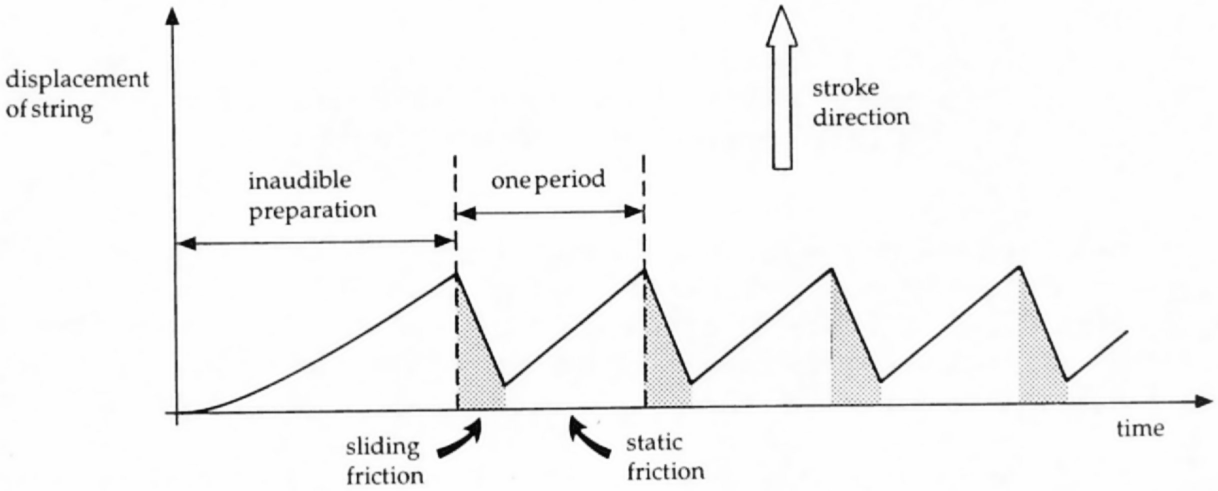

Fig. 10.4: Displacement of the string when bowed.

On account of this there will be at least 2 x 100 = 200 recoils per second, so that the sound will to a large extent consist of the frequency 200 Hz (G), which is an octave higher than the frequency (100 Hz≈GG) intended.

The wave pattern is formed in the course of the very first periods, as has been shown, and it is extremely difficult to alter it to any extent, once it is established. This is often experienced when playing: a string sometimes begins to 'whistle' or to produce a sound like a harmonic. In such cases it is very difficult to alter the sound without stopping, or changing the direction of the bow. What can be done however, is to reduce the bow speed (or increase the pressure) so much that all the wave forms get more or less 'stifled', and then continue the bow at the right speed (and pressure), whereupon a new and, it is to be hoped, better wave pattern can be formed.

10.5 THE RELATIONSHIP BETWEEN PITCH AND BOW SPEED

In 10.1, it was stated that there is a proportional relationship between bow speed and pitch. Now the principles have been explained, it is easy to prove this assertion. Two constants, however, must be assumed:

- The distance from the bridge to the point of contact, and
- The relationship between volume of sound and amplitude (the distance the string swings out to one side).

Returning to the example in 10.4, it was shown that a frequency of 100 Hz needs 100 recoils per second, and that the bow speed has to be 20cm / sec, assuming that each recoil is 2mm in length, while ignoring the bow's movement during slip.

If the bow is drawn across another string, lying beside the first, and this second string was tuned to 50 Hz (GGG), then the bow speed would have to be 10cm / sec, to produce 50 recoils of 2mm (10cm / sec = 2mm x 50 sec^{-1}), i.e. half as much as the bow speed previously used. (In a similar way, a string tuned to 75 Hz, or a fourth lower than the first string, would demand a bow speed of 2mm x 75 sec^{-1} = 15cm / sec, or in other words, a bow speed which was $^{75}/_{100}$ of the first.) There would thus be a **proportional relationship between bow speed and pitch.**

Remarks: In practice, the demands regarding pressure/speed of bow stroke will not be quite so absolute as they have been formulated here, because the string itself partly regulates the length of the recoils: if bow pressure increases independently of bow speed, the recoils (i.e. **both** the string's release point and the point where it again grips the bow hair) will be displaced, within certain limits, away from the centreline of the string, in the direction of bowing. **These limits of tolerance for speed/pressure are greatest when playing a long way from the bridge, and become progressively less as the bow approaches it.** If an even sound on different notes is to be obtained, care must be taken to keep at the same point within the limits of tolerance, because the tonal quality varies noticeably when one moves away from one tolerance limit towards the other.

In practice, of course, the ear becomes the arbiter of all these carefully measured physical factors, and the better trained the ear, the more perceptive the player will be.

For further reading see "The Physics of the Violin" by Lothar Cremer (The MIT Press, 1983, ISBN 0-262-03102-7).

10.6 BOWING EXAMPLES

In the light of what has been discussed, choice of bowings can now be considered with respect to the physical conditions known to exist.

Fig 10.6(i) **a** shows a minim d′, and a crotchet D, repeated in each bar. It can be calculated that the minims will need about twice as much bow speed as the crotchets, because of the octave interval between them. As the minims also last twice as long as the crotchets, they will theoretically need about four times as much bow as the crotchets, if they are to sound as loud.

Fig. 10.6(i)

If the passage is played with the bowings indicated **above** the notes and the bow is kept on the string, the third crotchet in each bar will inevitably sound too loud, or else the string will not be properly impelled on one of the notes. The passage implies the contrary (a heavier first beat and a light crotchet).

Look at the bowing which given **under** the notes. Here two notes are played on each bow, so there is nothing to prevent the bowing being organised so that the minims get four times as much bow (or even more, if we like) as the crotchets at the end of each bar.

If the musical context does not require sustained bow/string contact, the top bowing is perfectly satisfactory provided that the **bow is lifted** either after the minim and moved towards the frog before the crotchet is begun, or the crotchet is articulated at the tip and then the bow **lifted** so the next minim can be started at the frog.

Consider fig. 10.6(i)**b**. Here the problem does not exist. The frequencies of the minims and crotchets are reversed here, so that the two bow speeds compensate for the different lengths of the notes. In this case, the minims need no more bow than the crotchets, and the suggested bowing is therefore perfectly suitable.

Fig. 10.6(ii) **a** and **b** present just the same bowing problems as fig. 10.6(i) **a** and **b.** The highest notes in fig. 10.6(ii) **a** need about three times as much bow speed as the lowest one does. The bowing given **under** the notes solves this problem. The bow could also have been **lifted,** after the low note, and carried it to a starting point from where there would have been enough for all the tied notes.

In fig. 10.6(ii) **b** the problem does not arise because there is a balance between the frequency (or bow speed) and the duration of the notes.

Fig. 10.6(ii)

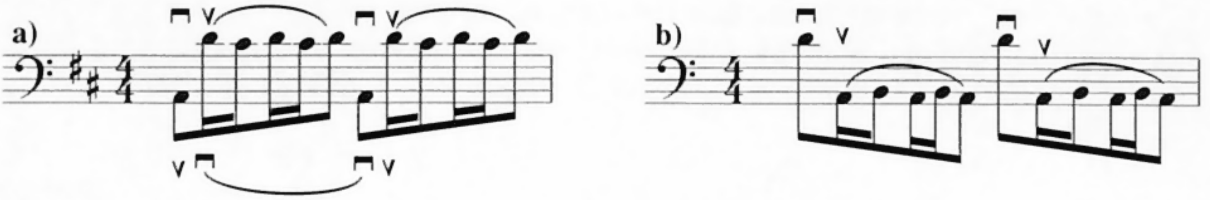

Fig. 10.6(iii)
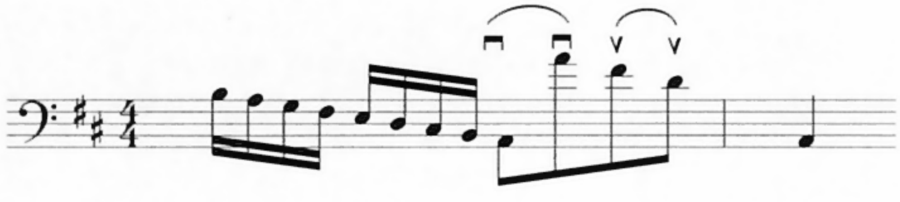
Fig. 10.6(iv)

Fig. 10.6(v)

Fig. 10.6(i)–(v): Choosing bowings: the relationship between frequency and bow speed should be taken into consideration.

Fig. 10.6(iii) shows an example (Dittersdorf Concerto No.2, first movement) of a similar bowing solution. Here the problem is to have enough bow for the three last quavers in the first bar. The semiquaver passage at the beginning of the bar is best played with the lower part of the bow. If the first quaver (AA) is played correctly (with little bow), an up-bow for the a′ will be rather too short, specially if one wishes to accentuate this note. But if the first two quavers are played with down-bows (as shown), one can use as much bow as one likes for the a′.

Fig. 10.6(iv) shows a rising legato passage. If the whole of the first bar is to be played in one bow, it is necessary to start with very slow bow speed, because the last two quavers will need about as much bow as the first five! In other words, the bow must not have got beyond the middle at the moment when the last quaver but one (g′) is begun. Try this example: if it is to succeed, the bow must be placed in advance rather near the bridge. (It can of course be moved even nearer, during the bar itself - see 10.10.)

If it is not expedient to play all the quavers in one bow, and they are divided into two, it will be an advantage to delay the change until after the fourth or fifth quaver (4+3 or 5+2), instead of the bowing given (3+4). In the same way, the upper bowing given in fig. 10.6(v) (3+5) is better than the lower (4+4).

How in the last resort one chooses to split the bow is of course also dependent on the melodic, harmonic and rhythmical considerations. It does no harm to take the physical factors into account as well.

Wherever possible, bowings should match those of other players in an ensemble situation and should be devised to accommodate breathing of singers or wind players as necessary.

10.7 BOWING ON TWO STRINGS AT ONCE

In order to play simultaneously on two strings tuned an octave apart (e.g. 100 Hz and 50 Hz), it is clear that one cannot bow at different speeds on both strings at the same time. Bow speed must be determined and the **bow pressure** adjusted so that the higher string gets shorter recoils than the lower.

For example, if one plays with low pressure on the higher string, one can produce 100 recoils of 1mm per second, which needs a bow speed of 10cm / sec. At the same time, by putting rather more pressure on the lower string, this can be drawn as much as 2mm sideways after each of the 50 recoils per second determined by the frequency. This implies a bow speed 2mm x 50 sec^{-1} = 10cm / sec - in other words, the same ideal speed as for the higher string. The needs of both strings have been satisfied simultaneously, **but with the result that the lower string sounds louder than the higher.**

If one wanted to formulate a simple rule (assuming that the length of the recoil increases in proportion to the bow pressure), one could say that **when playing double stops, the distribution of bow pressure between the two strings should be in inverse proportion to the relationship between the frequencies (pitches) of the two strings.**

In the case of an octave, for example, twice as much pressure is needed on the lower note as on the higher. Or, in the case of a major third, 1.25 times as much pressure is needed on the lower string, because the ratio between the frequencies of the two notes is 1.25 : 1. In the same way, a major tenth needs 2.5 times as much pressure on the lower string as on the higher, since the frequency of the higher note is 2.5 times that of the lower.

N.B.: Incorrect bow pressure is the most common cause of faulty intonation in double stops, especially in thumb positions. Many players use too much on the higher string - with the result that the pitch sinks or varies. In such cases the cause is very often to be found in the right arm, not the left hand, as one might easily imagine!

Even when the melodic line lies in the highest note of one or more double stops, bow pressure should be adjusted according to the difference in frequency, and the lower note played loudest. The top note will still be heard well, in spite of this.

10.8 CHOOSING THE POINT OF CONTACT

The bow's point of contact with the string is critical. If it varies, the pattern of overtones, the limits of tolerance for bow speed, and the capacity to play harmonics will all be altered, while the bow pressure and speed will have to be adjusted accordingly.

To take the last factor first, it can easily be seen that a string moves less away from its centreline, near the bridge and the nut where the vibration has less amplitude. This means, that when bowing near the bridge, recoils will be shorter, see fig. 10.8(i) the bow must be drawn more slowly if the pitch is to remain constant and recoils more frequent than one per period are to be avoided. (See 10.4 'Bow Speed'). In bowing close to the bridge, without altering speed or pressure, a point is reached where the sound breaks up. On the other hand 'normal' tone can be achieved right at the bridge, as long as bow pressure and speed are suitably adjusted.

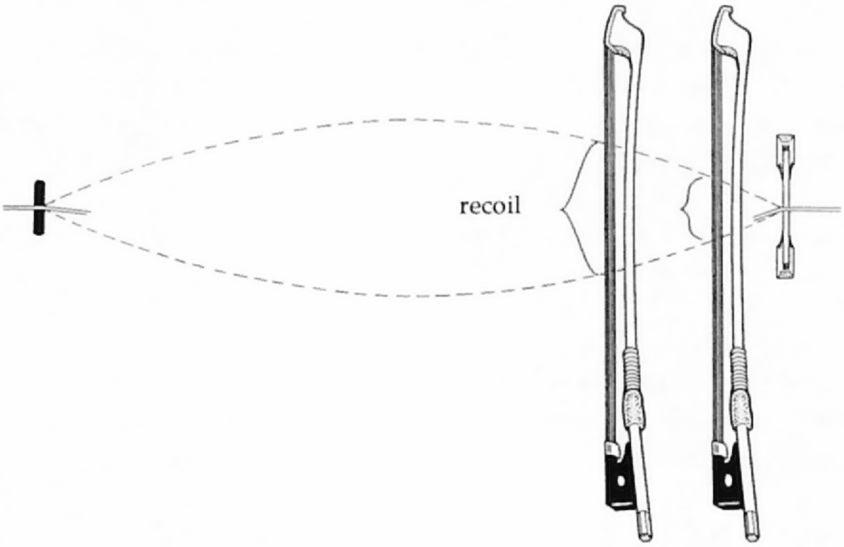

Fig. 10.8(i): When bowing near the bridge, recoils will be shorter.

A diagram (fig. 10.8(ii)) can best describe the relationship between the four elements:

- BOW SPEED
- BOW PRESSURE (arm weight)
- BOW DISTANCE from the bridge
- FREQUENCY (pitch)

If the string is to be 'driven' in the right way (with one recoil per period) these four factors must be in balance (within the limits of tolerance mentioned in 10.5).

If one of these factors is altered, at least one of the others must also be.

For example, it is a common fault to accentuate certain notes by increasing bow pressure alone. To obtain a free sound and unimpeded string movement, bow speed must be increased at the same time. As can be seen from the diagram, BOW PRESSURE and BOW SPEED are on opposite sides of the scales.

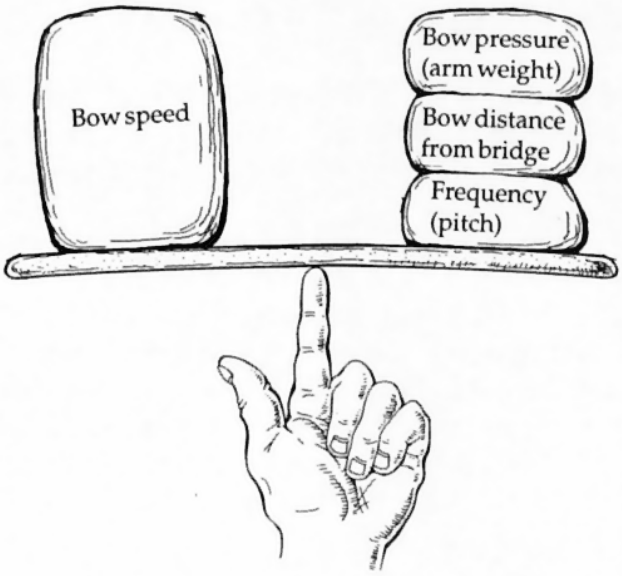

Fig. 10.8(ii): The ideal relationship between the four physical factors.

An increase in bow pressure could however also be compensated for by a **decrease** in the DISTANCE between the bow and the bridge. Moving the bow nearer the bridge requires more pressure (and consequently more friction) in order to draw the string an equal distance out to the side.

To gain full control of the movements of the string, and thereby the sound, these principles must be understood. The following experiments may help.

Experiment No.1
Choose a note of **constant pitch** (e.g. c′ on the G string), and try to maintain **constant speed** and **constant pressure** with the bow (change bows as necessary). These three factors are then static, but the fourth, **distance from the bridge,** can be varied.

Start with the bow over the fingerboard. While it is drawn evenly backwards and forwards, move it slowly down towards the bridge, until it finally reaches it. At the beginning, while the bow is some distance from the bridge, the sound will be strangled, then it improves; finally it breaks up as the bow reaches the bridge.

Observe which point of contact gave the best sound – and move the bow there. If the exact point is not located straight away, continue until it is found. Keep the bow speed, bow pressure and pitch as constant as possible and repeat the experiment with various notes on different strings.

The ear learns to detect very quickly which side of the 'ideal point of contact' the bow is playing and the necessary adjustment can be made spontaneously.

Experiment No.2
This time a different variable is chosen. **Pitch, bow pressure** and **point of contact** are kept constant, while **bow speed** is varied from zero to rather fast.

As in the first experiment, the optimum combination of factors will soon become apparent. Here also, try to re-establish optimum bow speed immediately afterwards.

It is important to acquire some personal reference points, so that a quick adjustment can be made – in the right direction – if one does not hit the nail on the head straight away.

Since there are **three** variables for any given pitch, it is clear that any two may be chosen, while the third has to balance (compensate for) the first two. What will change according to the variable, is tone colour and volume of sound. Both of these are equally important to have under control, and one should therefore practise the production of different tone colours **with every possible dynamic variation.**

For example, practise soft notes with a sharp quality of sound (near the bridge – very little bow speed). Then practise soft notes with a soft tonal quality (further from the bridge – considerably more bow speed), and here it is important that the **tone quality is soft the whole time – also when changing bows!**

Notice how, in consciously combining differences in volume with nuances of tone colour, the instrument's dynamic range appears considerably enlarged.

One occasionally hears it said of certain violinists that their pianissimo "carries right to the back of the hall". The physical explanation for this is probably that they objectively play nearer mezzoforte than pianissimo, dynamically, but they keep the tone colour soft (producing fewer high overtones). The cellist Rostropovitch is a fine example of a musician who fully masters – and uses – the large spectrum of tonal variation a bowed instrument can produce.

10.9 TONE COLOUR

It has been shown above how tone colour can be varied by choosing different contact points for the bow. This can be explained in rather more detail.

The body of a stringed instrument acts as an amplifying soundbox, which sets the air in vibration. Measurements show that the body itself does not amplify frequencies which are not already present in the string. Even a Stradivarius will sound dry and dull if its strings do not move in patterns which include sufficient overtones.

When, for example, a violin open G is sounded, all the notes shown in fig. 10.9 will be produced (overtones), although they will vary in volume. The frequency of each overtone will be a multiple of the fundamental frequency of about 200 Hz (400, 600, 800, 1000 Hz etc.).

The note G (which is what we want to hear) will probably not even be the one that sounds loudest. Measurement would show that the body of the instrument amplifies this

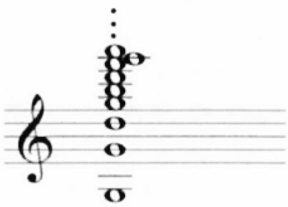

Fig. 10.9: Harmonic frequencies of the note G (bottom note).

frequency very little, while g' – an octave higher – will be amplified much more. All the same, the ear will perceive this collection of notes as **one** note – G. It will do so because G is the only note which has this particular combination of overtones.

The mutual dynamic relationship between the fundamental and the overtones gives the instrument its characteristic tone quality, and is determined by the physical (amplification) qualities of the bridge and the body of the instrument. The frequencies however **must** be present at the point where the sound is formed; in the string.

(When one uses vibrato, the pitch varies somewhat, and the mutual dynamic relationship between the various overtones will vary in time with the pitch. This is a considerable advantage because one can thus make a greater number of overtones clearly audible than if one had kept the pitch static. When therefore one says that the vibrato makes the tone "bigger and richer", this is really much more than a mere phrase.)

The bow's point of contact will largely determine which frequencies are in the string, and their relative energy content. The nearer the bridge the bow is placed (or rather – the smaller this distance is, compared with the total vibrating length of the string), the greater the part of the energy in the string which manifests itself in the form of high overtones.

This is worth remembering, since, ideally, the bow should always divide the string in the same proportions, to produce an even quality of tone. For example, if one plays two consecutive notes an octave apart, on the same string, the bow's distance from the bridge should be half as much for the upper note as it is for the lower.

In practice this is too complicated, and because of constantly changing intervals, one has to compromise. Nevertheless, it is specially important to play near the bridge when the left hand is in the higher positions. (This of course applies regardless of which string one is playing on.) Very many players produce a dull and strained sound when playing in the upper register: dull, because the string is divided into a ratio which does not bring out the higher frequencies sufficiently – and strained, because the string is being driven by a bow moving rather too slowly in relation to contact point / bow pressure / frequency, and which is therefore often in danger of strangling the vibrations in the string. The rule to remember is: **High positions need the bow close to the bridge. Get it there in advance!**

Another phenomenon is worth keeping in mind. When, in thumb positions, one changes string from G to D, the D string often has a tendency to sound dull compared with the G. The transition can be camouflaged by using minimum bow pressure on the G string (within the limits of tolerance mentioned in section 10.5), and comparatively greater pressure on the D, preferably rather nearer the bridge, to compensate for the overtones which would otherwise be lost on the thicker string. It is good practice to try to produce exactly the same quality of tone on the same note, played alternately on different strings.

N.B.: Relatively hard resin helps to bring off this kind of tonal variation. Soft resin (such as most so-called "Double Bass" resin) narrows the limits of tolerance for bow pressure / speed / contact point. This is specially noticeable in high positions, where these limits are already very narrow.

Several physical factors influence the performer's powers of projection (the note's ability to travel to the listener)

- Distance
- The ability of the hall to reflect the various frequencies
- Sounds from other sources, which compete for the listener's attention

In a completely 'dead' hall, the transmitted energy diminishes rapidly with increasing distance from the performer, due to absorption by the walls and other surfaces. The walls of a good concert hall will be much better for reflecting sound, but higher frequencies are still not always carried to the audience as effectively as lower ones. These higher frequencies are essential for the listener's clear perception of rapid passages and finer details. So the player must take care to produce enough overtones to compensate for those 'stolen' by the hall.

When several instruments are played together, the ones most clearly heard will be those which are the strongest within any given part of the total range of frequencies. For example, when a violin and a trumpet are played together, the violin will be clearly heard, even if the trumpet is played much louder. This is because, while the sounds of the trumpet consist mainly of frequencies between 200 and 4000 Hz, those of the violin include frequencies ranging from 200 to more than 12,000 Hz, and therefore meet very little competition above 4000 Hz.

Accordingly, even a faint sound from a double bass will get through to the listener if it includes frequencies lower than 200 Hz.

However, when playing with a piano, it is the higher frequencies of the double bass which tend to be the most 'competitive', since the piano, although able to produce the same low frequencies as the bass, cannot bring out the highest overtones with the same energy as the bowed instrument.

10.10 MOVING THE POINT OF CONTACT

It has been shown how important it is to vary the bow's point of contact while playing. This should not be done with the bow at an angle of 90° to the string, as it tends to make the hair lose its grip, and the tone quality is adversely affected. By studying fig. 10.10 **a,b,c,d,** one can see how the point of contact can be moved down or up by adjusting the bow. By trying out these four combinations of angle and direction, it will soon be seen that the point of contact can very easily be altered, without any incidental noise.

Do not confuse **bow angle** with **direction of bow stroke.** The bow is angled by moving the hand nearer to or further from the bridge, whilst using the point of contact as a sort of pivot. (This can be done either while the bow is at rest, or when playing.) The stroke is then made with the **bow** at an oblique angle to the string, but in a path at right angles to it. (This means that the frog and the point of the bow follow parallel paths, at different distances from the bridge.)

When the new point of contact has been reached, the bow can be straightened so that the stick will once again lie at right angles to the string.

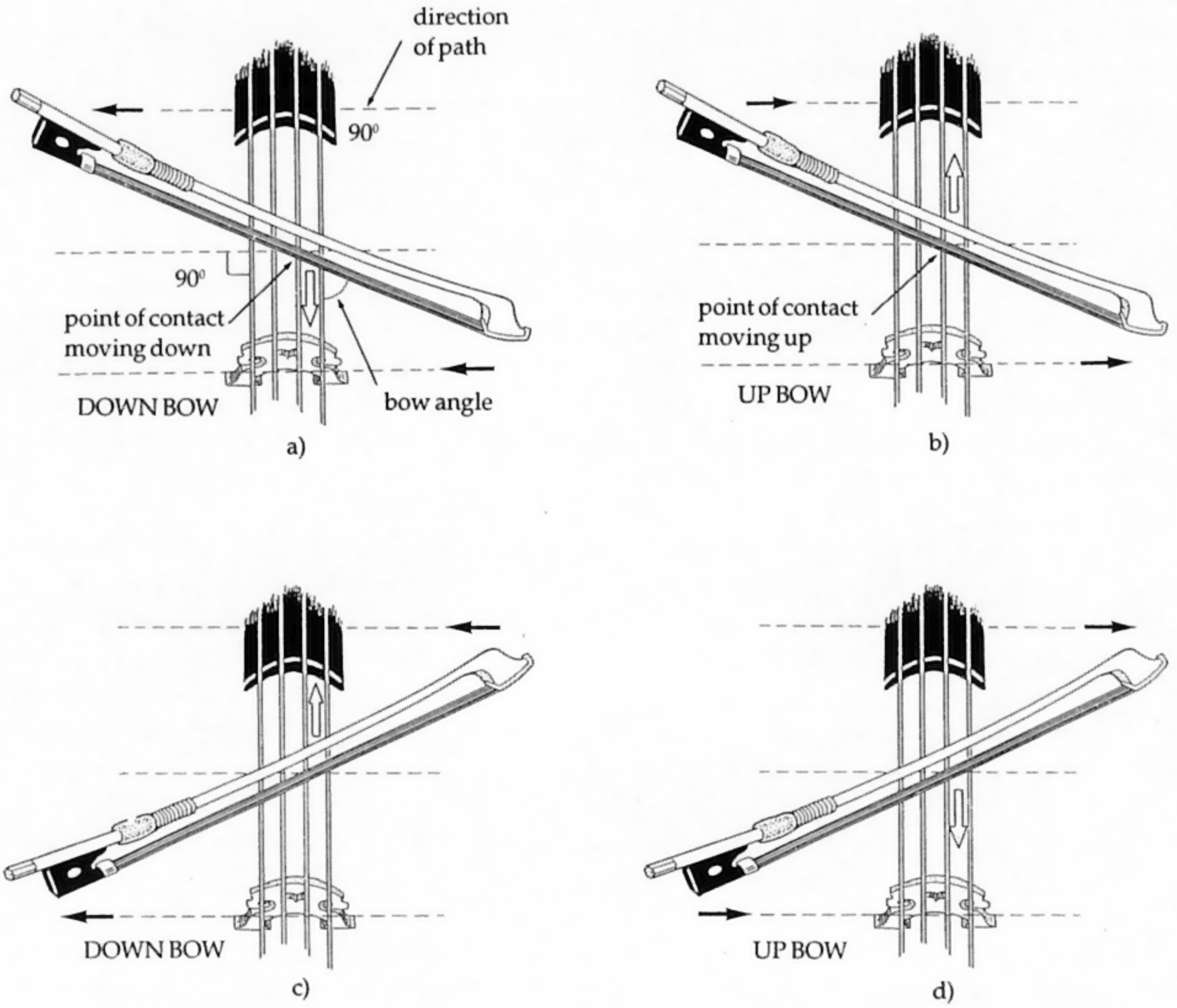

Fig. 10.10: To maintain a first rate sound while altering the distance from the bow to the bridge, the bow should be angled. The paths of the different parts of the bow (i.e., the stroke) always make a perfect 90° angle to the string (see black arrows). The angling of the bow causes the point of contact to move (see white arrows).