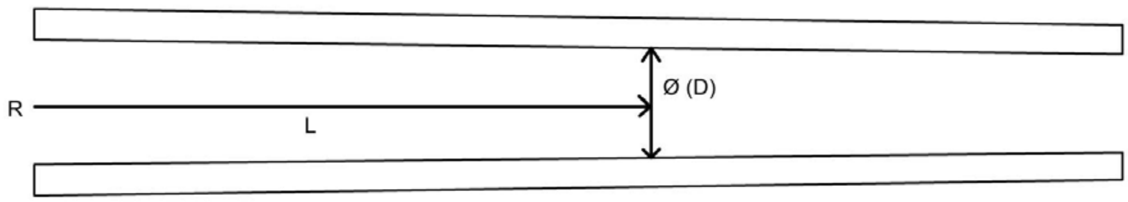
FoMRHI Comm. 2032 **Jan Bouterse**

Making woodwind instruments

2b- Internal dimensions: tools, techniques and registration

In the study of woodwinds and the process of making copies it is very important to know as much as possible about the internal dimensions of the instruments: the profiles of the bores very much define their character. Other internal measurements concern the properties of the tone holes and mouth hole (in traversos) and for recorders various aspects of the windway. By contrast with external measuring, which you can do with tools which you find in every local DIY shop, you need special equipment for assessing internal dimensions. Some of them you can make yourself, or you must adapt tools which you can buy.

There are four or five types of tools or techniques to take internal measurements:
A- tools with a fixed (preset) diameter: insert it in the instrument as far as it goes till it touches the wall of the bore (that applies for bores with a tapering profile) and measure L for that point;
B- tools with an adjustable measuring system: bring the tool in the instrument to the desired position L, and measure D at that point;
C- measuring machines where L and D are assessed together with special equipment;
D- taking casts, for instance of tone holes or windways of recorders;
E- using X-ray photos or CT-scans.

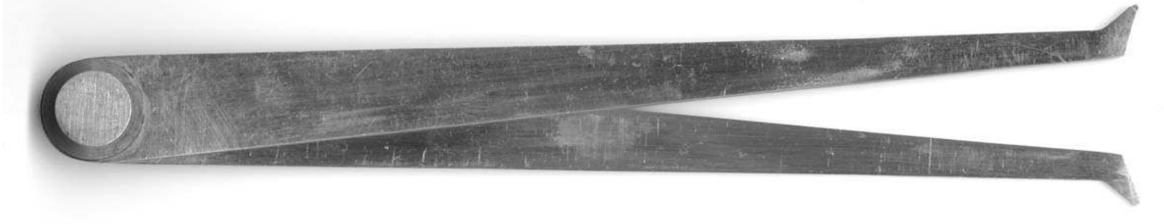


Before discussing the tools, it is necessary to know a few facts about measuring.
1- Each record of an internal measurement consists of two components: the position within the part of the instrument, measured as the distance (L, length) to a reference point (R, in most cases one of the ends of the instrument where the measuring tool is inserted), and perpendicular to A, the diameter (Ø of D) or height (H) at that point.
You can measure Lmin and Lmax for diameter intervals of - for instance - 0.1 mm (with type-A tools). Or you can measure Ømax and Ømin (or Øhor and Øver; hor and ver means horizontally ↕ or vertically↔) at distance intervals of 5 or 10 mm. The choice of diameter and length intervals depends on the size of the instrument.
2- Many woodwind instruments tend to shrink in the course of the years, resulting in cross sections (which of course were originally round) having a more or less oval shape. That means that it is necessary to take more measurements for finding the maximum and minimum diameters at each point.
3- You have also to be aware of the relation in accuracy between L and D. An example: for a conical bore which narrows 1 mm over a distance of 40 mm, it means that an inaccuracy of 0.05 mm for D results in 2 mm for L. The consequence is that there is in most circumstances no need to measure L more accurately than 1 mm.

4- Taking measurements can be dangerous: when they are pushed with too much force into the bore, even tools with rounded tips can leave marks, especially when the wood has become soft, for instance by decay. That's why it is no longer allowed in many collections to take internal (and also various other) measurements of woodwind instruments.

The tools

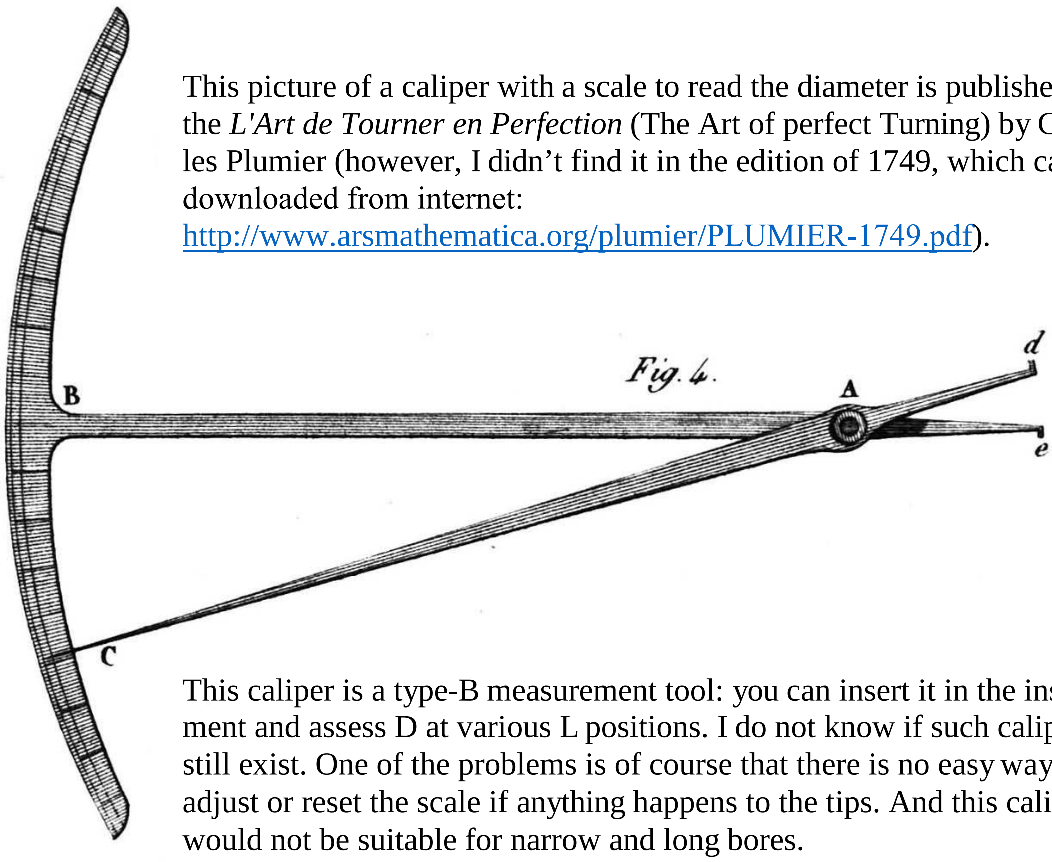
The traditional way of measuring internal dimensions is with a caliper.



The two legs of this caliper have to be pushed by hand into the desired position. That must be done with some force, because both legs turn around the bolt with some friction; this to avoid unintentional movements.

I have ground and polished the tips at the end to prevent scratches. It is best to be used as a type-A measuring tool: thus presetting the desired D and then inserting it in the instrument. But measuring bore profiles with such a caliper is rather awkward and inaccurate: you have to determine D and L with other measuring tools. And it is only usable in relative wide and short instrument parts.

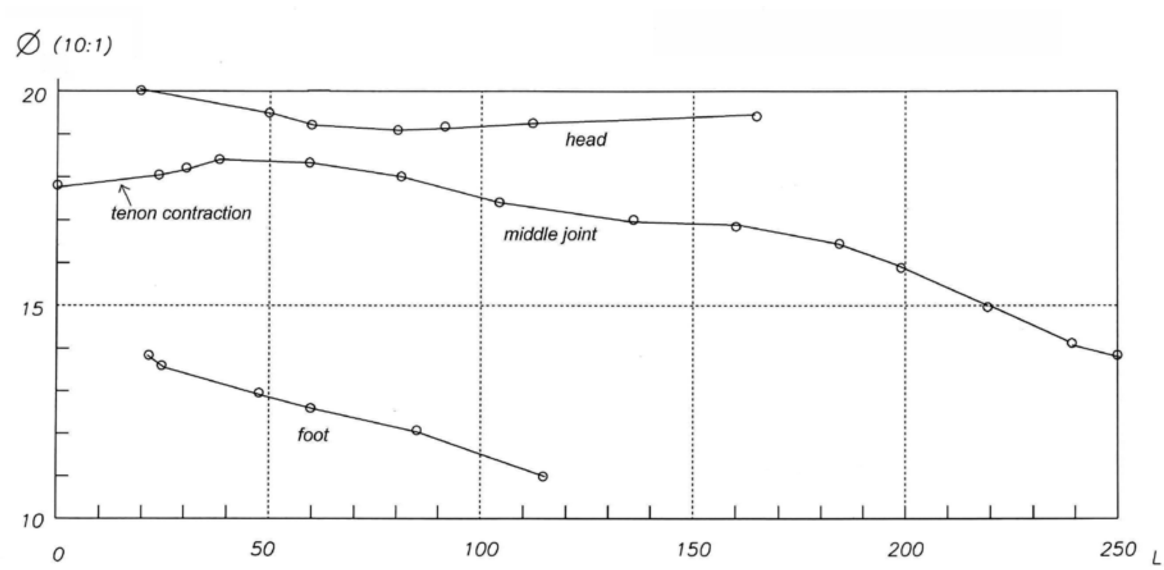
This picture of a caliper with a scale to read the diameter is published in the *L'Art de Tourner en Perfection* (The Art of perfect Turning) by Charles Plumier (however, I didn't find it in the edition of 1749, which can b downloaded from internet: http://www.arsmathematica.org/plumier/PLUMIER-1749.pdf).



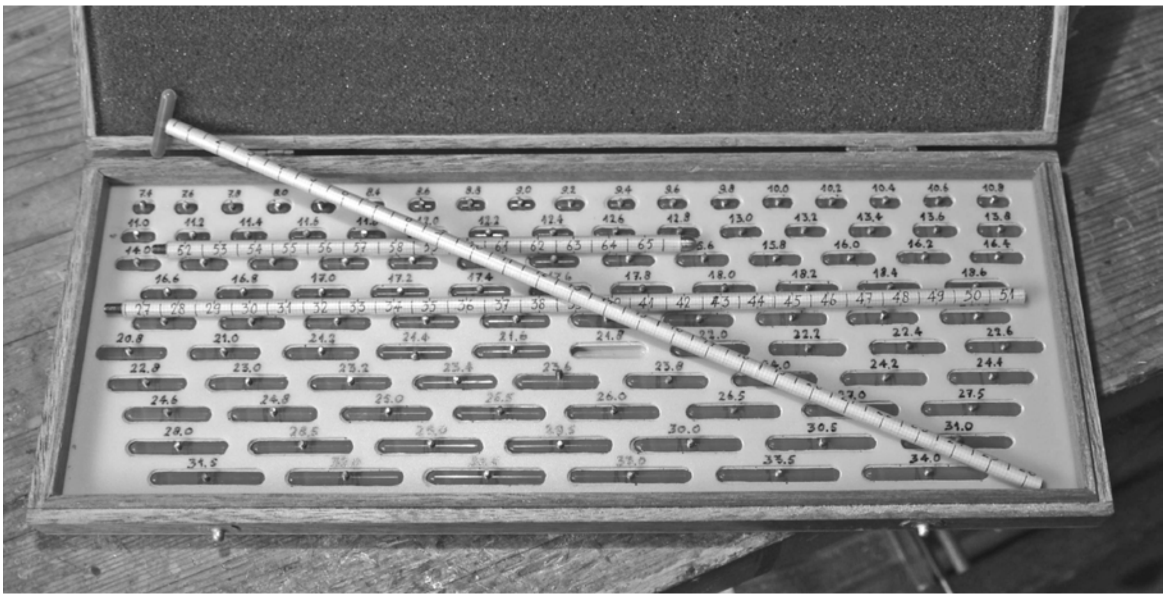
This caliper is a type-B measurement tool: you can insert it in the instrument and assess D at various L positions. I do not know if such calipers still exist. One of the problems is of course that there is no easy way to adjust or reset the scale if anything happens to the tips. And this caliper would not be suitable for narrow and long bores.

The calipers in the photo above have a spring and a setscrew. That makes it easier to set them in the desired position. The caliper on the left can be used for bore measurements, also where the bore gets (somewhat) wider after a narrower entrance (for instance a tenon contraction, see graph next page).

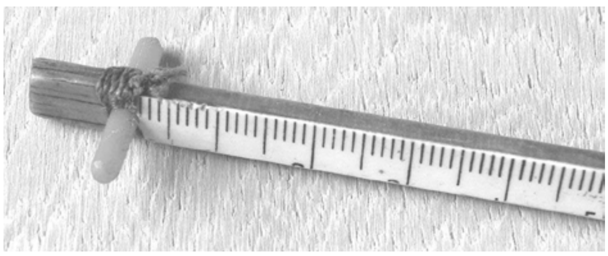
I made the legs of this caliper longer and attached new plastic tips with rounded tops. I use this caliper for instance for measuring the diameter of the bell of baroque oboes, where the bore is wider just after the rim of the bell.



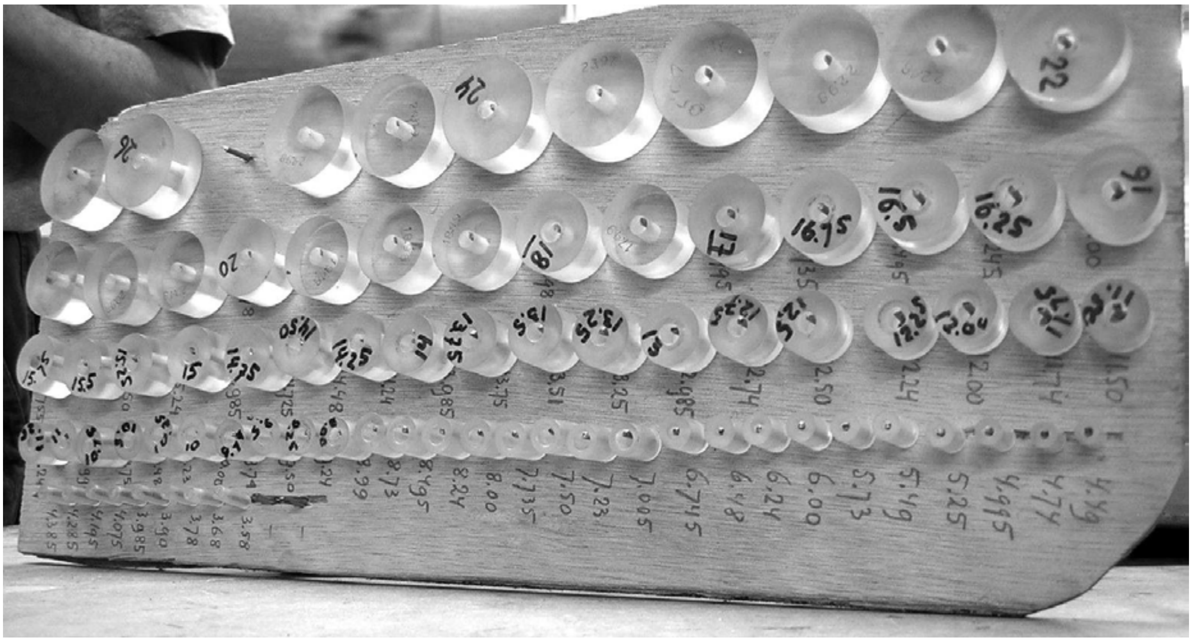
Graph of the bore of an alto recorder by Thomas Boekhout (Bellerive Museum, Zürich, Switzerland). The middle joint shows a contraction at the upper tenon. It is not possible to measure the wider section of the bore after the contraction with type-A tools.



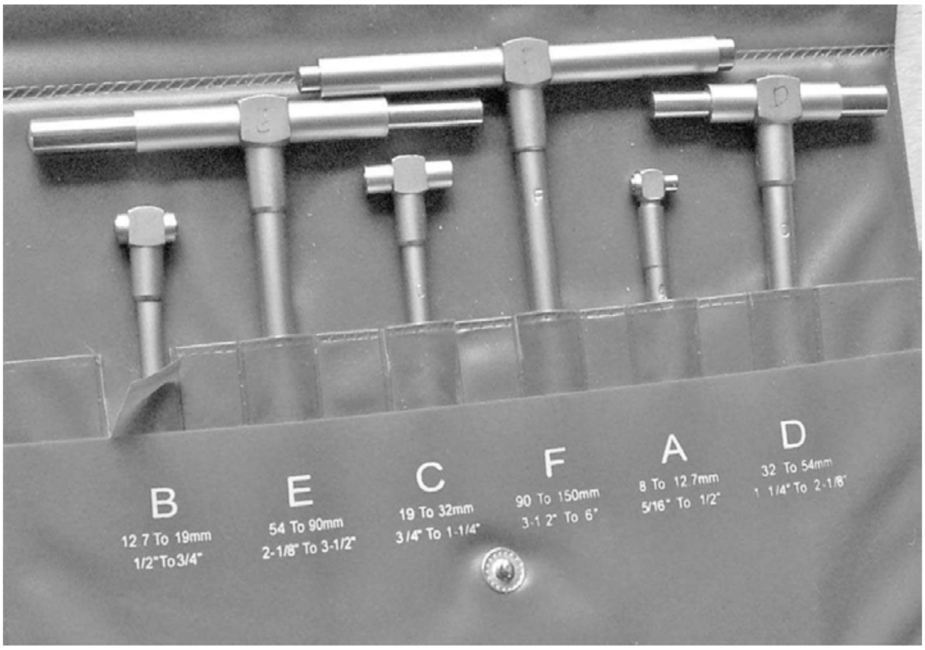
A simple way of measuring bores is this type-A tool where you attach sticks of fixed diameters onto a ruler (on the photo above, a rod on which is a piece of paper with a divisions in centimeters). This set is made by Jos Everts (Amsterdam), who sells them for specific instruments (in this case a set for baroque oboes).



I have also made such sets myself: with brass and with plastic sticks (these came from a cheap spillikins set), with rounded tops, from Ø 10 to 20 mm with steps of 0.1 mm. Important: you must keep the set in good order.



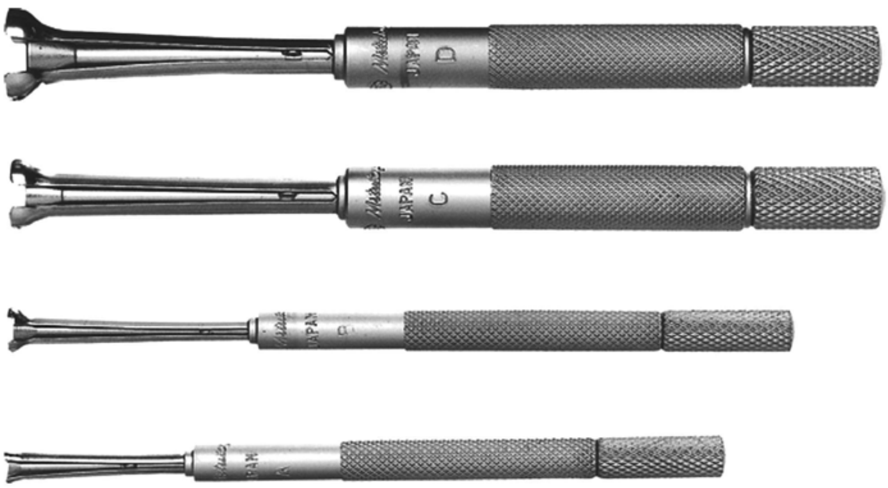
I have seen several other systems of type-A measuring tools: on the photo above a set with measuring discs in acryl plastic, made on a lathe. The owner of the set has tried to turn the discs in steps of 0.25 mm, but had in the smaller diameters some minor deviations. The discs on the photo are perfectly round and cannot be used to measure Dmax and Dmin in ovally shaped bores. The edges of the discs are also rather sharp. It is of course possible to remove some material from the sides of the discs, they can be used then in more situations.



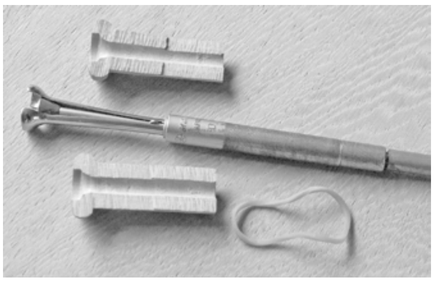
telescopic gauges

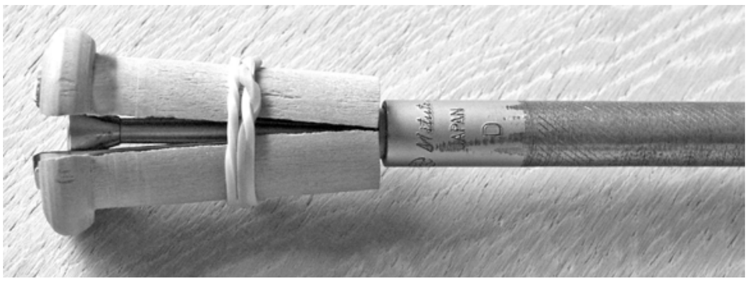
Instead of fixed systems, you can use adjustable measuring tools, such as telescoping gauges. These gauges are cheap and have polished surfaces to their metal tips (which is in my opinion always better than rough surfaces of some plastic tools). There are, however, some problems. The gauge expands in a bore or hole to be measured (it locks in place and must then be removed to determine final hole size using a micrometer or vernier calipers). But the spring mechanism which releases the gauges does that with some force, and that could damage the instrument. It is better to preset the gauges in the beak of a modern Vernier caliper and then use it as a type-A tool. The other problem is that these telescopic gauges are rather short. I have made some of the gauges of my set much longer, by making a screw thread on the lower end and put a connection joint on it which a threaded rod is mounted (photo right). It must say that I was glad to have a metal lathe to do the job properly. But it can also done with hand tools.

The smallest diameter of the telescoping gages is about 8 mm. For smaller diameters I use a so-called small hole gage set by Mitutoyo (series MM 154-902, see photo below), covering the diameters between 3 and 13 mm.



These gauges - which are much more expensive than the telescoping gauges mentioned before - have no spring mechanism, you simply turn the knob at the right side (in the picture) which expands the polished half-round tips at the left. I have also made these gauges longer and use them quite often. It is a pity that these versatile gauges are not available in larger diameters, but I have found a simple solution for that: see the photos below.





With some extensions, made of wood, simply fitted with a rubber band, you can arrange all desired diameter sizes.
The disadvantage of all these types of gauges is of course that you must take measurements on the tools (to assess the diameter) and that you have to find a simple system to establish the length: how far the tool was inserted in the instrument.

I have tried to make expanding gauges myself, but was not satisfied with the results: it is rather difficult to work on such small bits of metal and to finish them neatly.

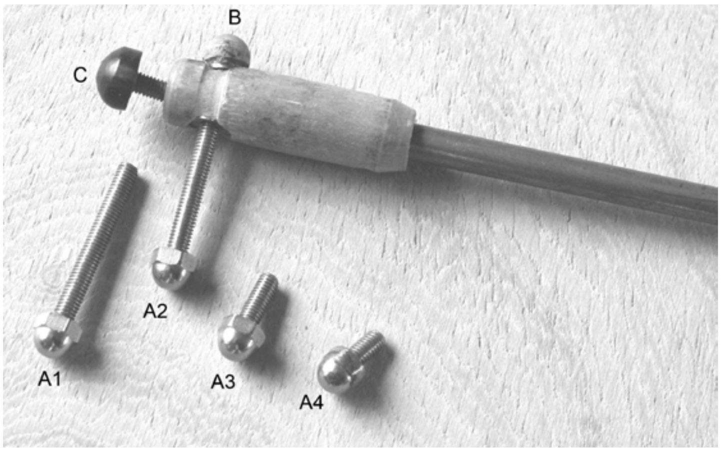
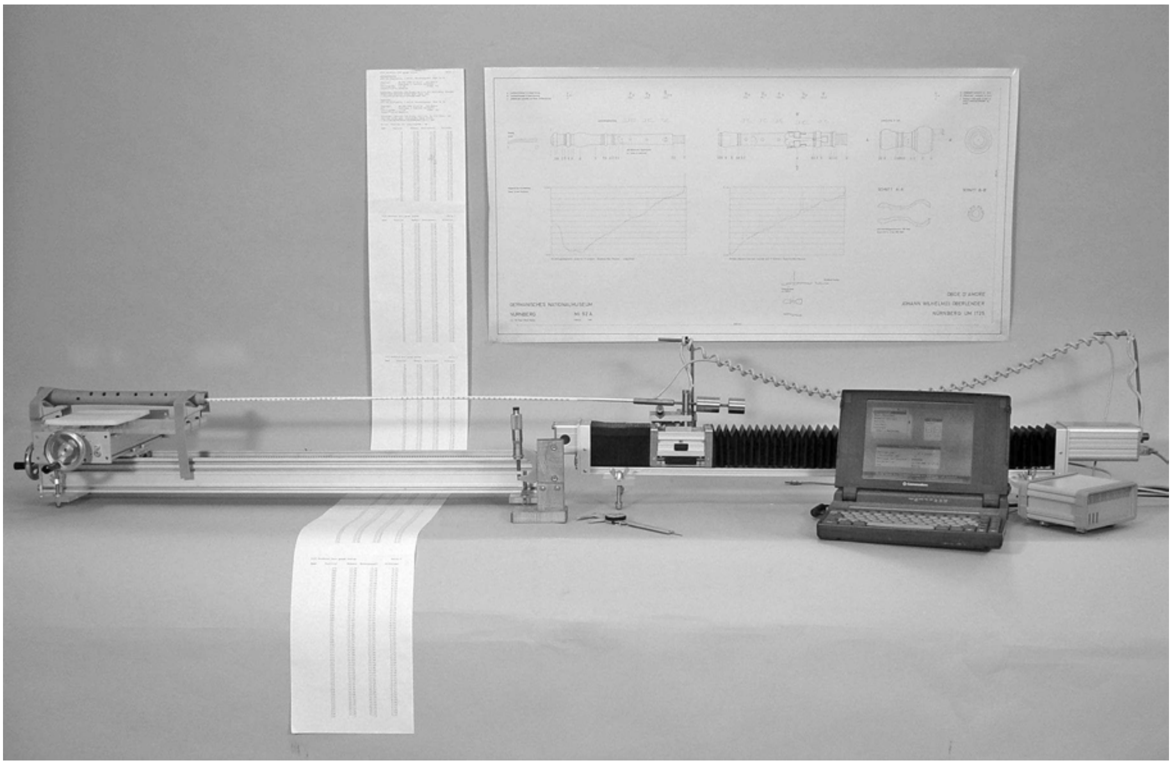
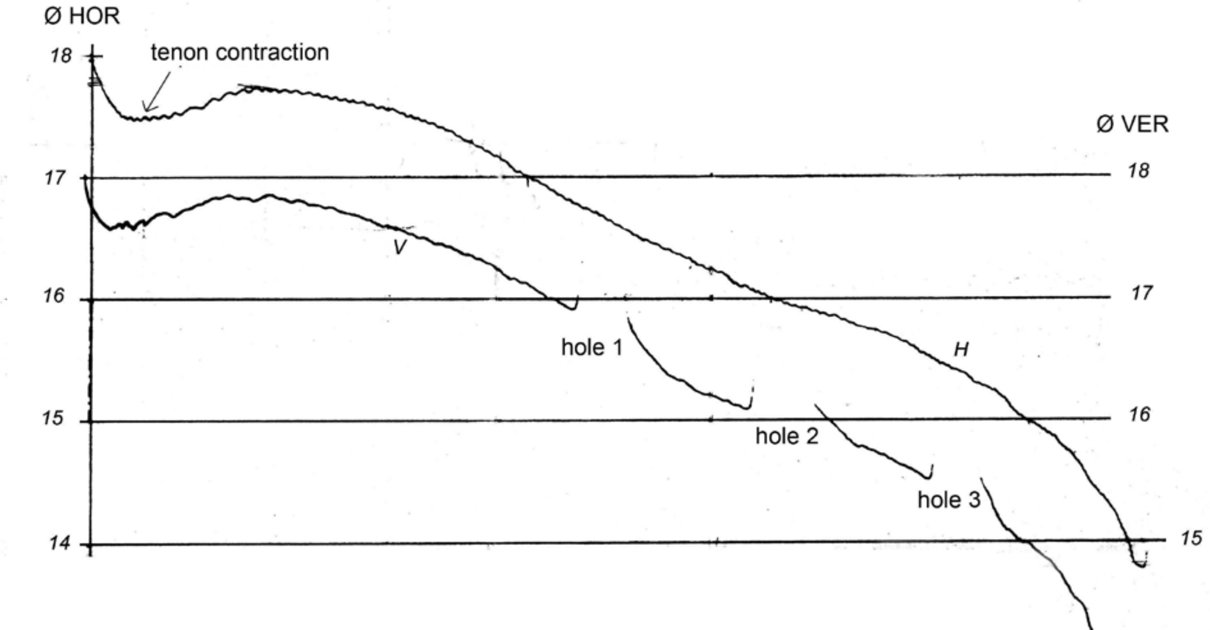


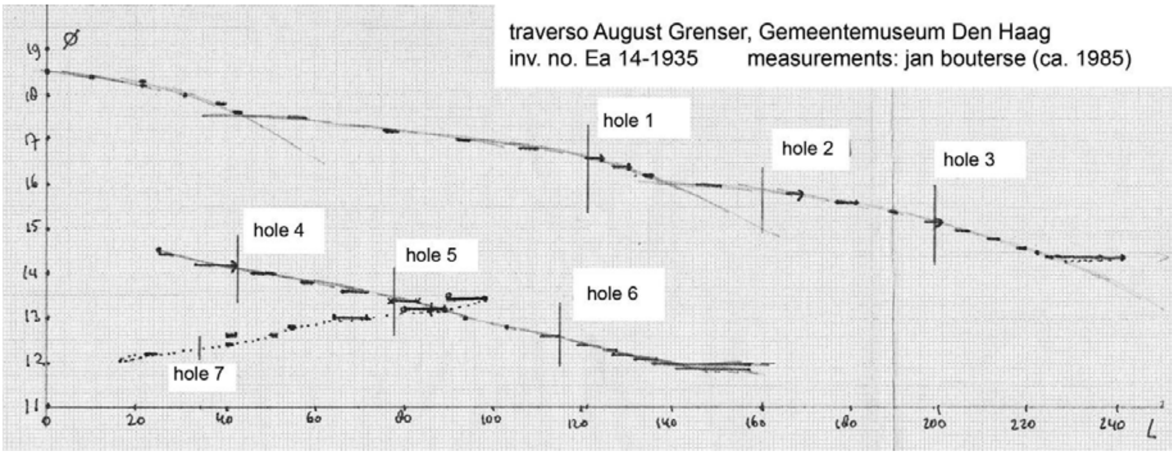
Photo left: a simple measuring tool with exchangeable bits (A1 to A4). They can be set accurately by turn- ing, and fastened with knob C. *Size of the screws: M3*



On this photo (GNM/IKK, provided by the Germanisches Nationalmuseum in Nuremberg, Germany) we see a modern bore measurement equipment in action. It was originally developed by the American traverso maker Rod Cameron, and in some parts adapted by the museum. An instrument part is positioned horizontally in the holder at the left side.
The holder with the instrument moves on a rail to the right and passes so a rod with a sensor or tracer (not visible on the photo) which makes a very gentle contact with the bore and measures the deflection at that point. It gives an electrical signal to the computer at the right, which translates that signal into a graph or a table with measurements.
This a type-C tool, which provides both L and D measurements. It is a very sophisticated way of assessing bore profiles. But the preparations for a measuring session must be done with great care and will take some time: putting the instrument in a perfect horizontal position is not easy, there will also be problems with crooked (curved) parts.

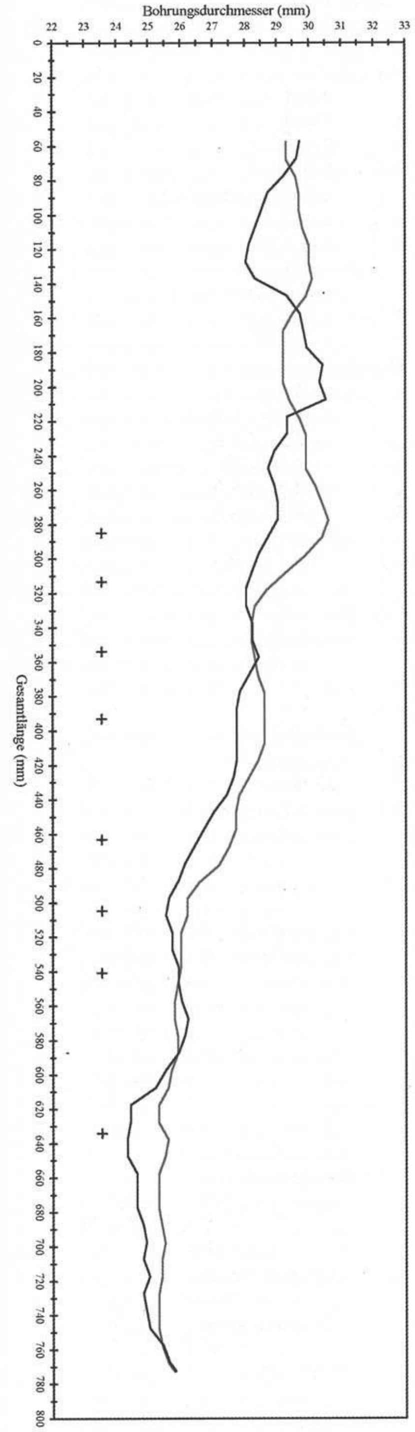


This is the result of a measuring session with the equipment in the museum in Nuremberg. We see the bore graphs of an upper middle joint of a baroque traverso by August Grenser. Use the Y-axis on the left for the horizontal diameters, and the axis on the right side of the graph for the vertical diameters. It is obvious that the tracer flipped in the finger holes: just a small part of the undercutting is visible. See also the contraction at the upper tenon. This traverso has seven 'corps de rechange' all of them have these contractions. On my (legal) copy of the bore profiles of this traverso is no X-axis; the drawing is however printed in a 1:1 scale.



This is a graph of the bore of a traverso by the same maker, in the Gemeentemuseum in Den Haag. I have standardized my bore graphs: the diameters (Y-axis) on a 10:1 scale with the lengths (X-axis). That makes it easier to compare the graphs: just put two papers on each other and hold them against the light. The measuring was done with a type-A tool, with intervals of 0.2 mm. The graph of the upper joint may suggest that Grenser has used three separate reamers: the first going to L40, the second to L140, a third one to L210. But maybe I joined up the measured diameters too subjectively. The last 30 mm of this joint are cylindrical. The bore of the head of this instrument is cylindrical: the diameter is about 18.2 mm.

SAM 158: Gesamtansicht.

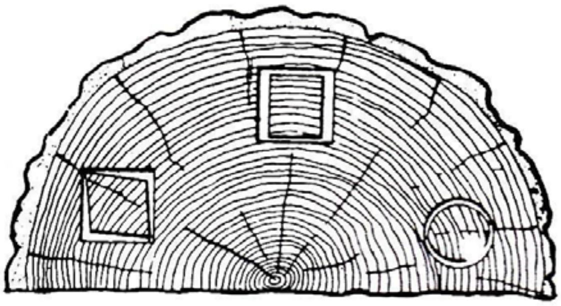


SAM 158 Fig. 1: Graph.

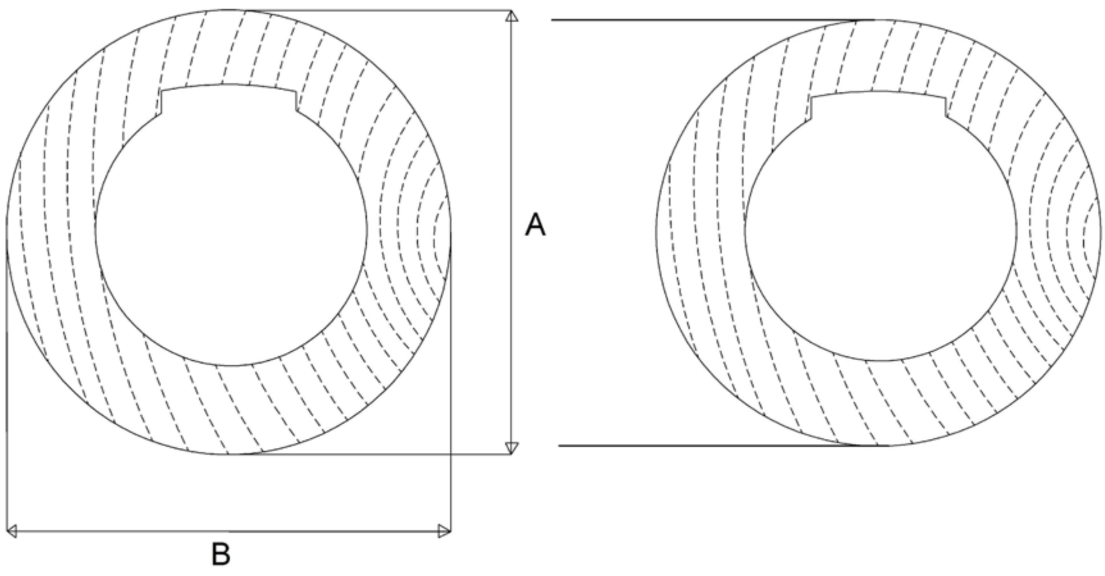
L	d /	d \
0,0	29,3	29,7
10,0	29,3	29,6
20,0	29,6	29,2
30,0	29,7	28,7
40,0	29,7	28,5
50,0	29,8	28,3
60,0	30,0	28,1
70,0	30,0	28,0
80,0	30,1	28,3
90,0	29,9	29,3
100,0	29,5	29,7
110,0	29,2	29,8
120,0	29,2	29,9
130,0	29,2	30,4
140,0	29,2	30,3
150,0	29,4	30,5
160,0	29,7	29,3
170,0	29,9	29,3
180,0	29,9	28,9
190,0	29,9	28,7
200,0	30,2	28,9
210,0	30,4	29,0
220,0	30,6	29,0
230,0	30,4	28,7
240,0	29,9	28,4
250,0	29,3	28,2
260,0	28,7	28,0
270,0	28,3	28,0
280,0	28,2	28,2
290,0	28,2	28,2
300,0	28,3	28,4
310,0	28,4	28,1
320,0	28,6	27,8
330,0	28,6	27,7
340,0	28,6	27,7
350,0	28,6	27,7
360,0	28,4	27,7
370,0	28,1	27,6
380,0	27,8	27,4
390,0	27,7	27,0
400,0	27,7	26,7
410,0	27,5	26,4
420,0	27,2	26,1
430,0	26,6	25,9
440,0	26,2	25,6
450,0	26,2	25,5
460,0	26,0	25,7
470,0	26,0	25,7
480,0	26,0	25,9
490,0	25,9	25,9
500,0	25,8	26,0
510,0	25,8	26,2
520,0	25,9	26,1
530,0	25,9	25,9
540,0	25,7	25,5
550,0	25,6	25,2
560,0	25,3	24,4
570,0	25,3	24,4
580,0	25,6	24,3
590,0	25,5	24,3
600,0	25,3	24,6
610,0	25,3	24,6
620,0	25,3	24,6
630,0	25,4	24,8
640,0	25,5	24,9
650,0	25,4	24,8
660,0	25,4	25,0
670,0	25,3	24,8
680,0	25,3	24,9
690,0	25,3	25,0
700,0	25,4	25,4
710,0	25,6	25,6
715,0	25,8	25,8

From: Die Renaissanceblockflöten der Sammlung alter Musik-instrumente des Kunsthistorisches Museum (Vienna 2006).

Adrian Brown used similar equipment for measuring the bores of the famous collection of renaissance recorders in the Kunsthistorisches Museum in Wien (Austria). He did not take measurements in horizontal and vertical direction, but diagonally: \ and / . Doing so he avoided the problems with the measurement equipment going into the fingerholes.
The graph on the previous page shows the big differences on some places (up to 2 mm) between the bore diameters at the same L position. The lines in the graph are given in the book in different colours, which could not be rendered here. But it is clear that Ømax and Ømin change positions sometimes. It is likely that the bore was made with so called spoon reamers, which give sometimes irregular bore profiles. However, Adrian Brown points in the description of this bass recorder to the rather wild structure of the wood (a fruit wood?) and presumes that differences in shrinking of the wood is the cause of the irregularities.
Nota bene: On the graph is L-0 the top of the instrument, in the table however L-0 is at about the window. The block was not removed when the bore was measured.

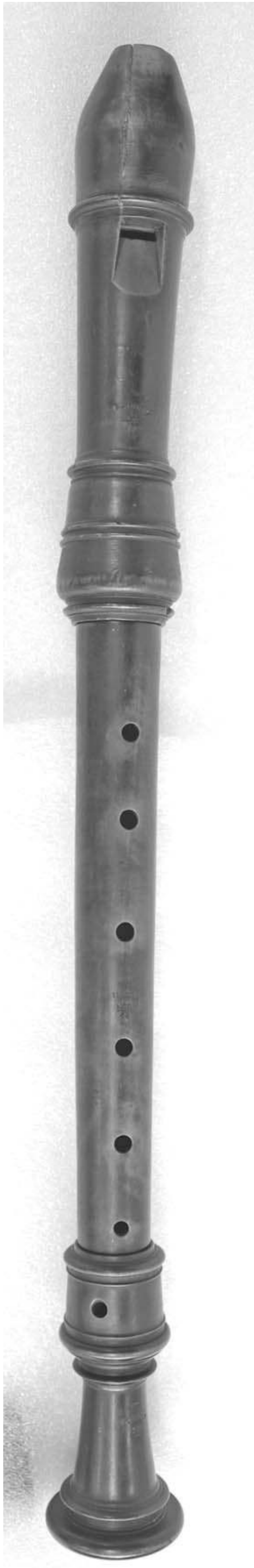


I have observed that shrinking of the wood can give quite unpredictable effects. Wood will shrink when it dries, and the process of drying continues over long periods. Shrinking is stronger parallel to the growth rings (in tangential direction) than perpendicular to those rings (in radial direction), see picture left.



On most (but not all!) historic recorders the windway and labium are situated at the radial face of the wood (see drawing), which means that over the years Ø-A will decrease more in size than Ø-B. For European maple wood, the shrinking from fresh wood to absolutely dry is 8% in the tangential, and 3% in the radial direction. On some baroque bass recorders heads I have seen that close to the window (block and labium) the wood has worked much more than lower on the head. It is important to take comprehensive measurements, not only in the bore, but also at the outside, with maximum and minimum values precisely recorded in relation to horizontal and vertical positions. That is the only way to reconstruct the original dimensions of the instrument.

Terton alto recorder, middle joint, Boers Collection Rijksmuseum Amsterdam, Inv. No. BK-NM-11430- 94 (ex-Gemeentemuseum Den Haag, Inv. No. Ea 31-x-1952).

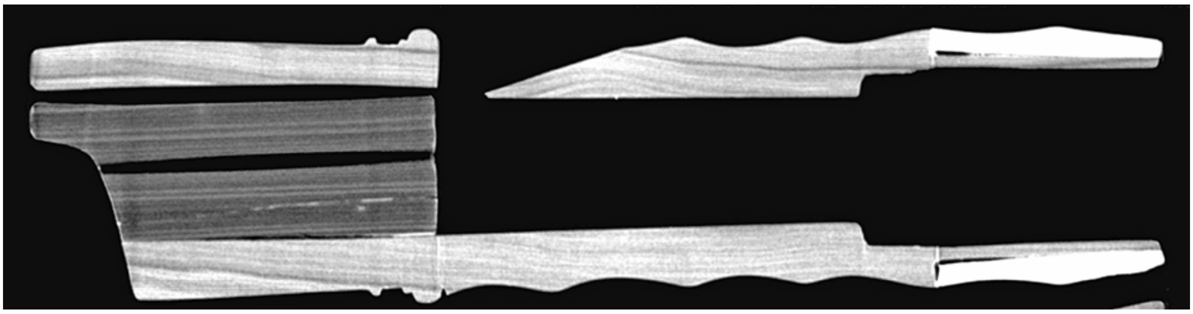


Type-A measuring (Jan Bouterse, c. 1980)	Type-B-measuring (after Charles Stroom 1985)
Ø - Lmin/Max	L - Ømin/max
17.8/18.9 - 0	0 - 17.90/18.95
18.6 - 0/8	5 - 17.80/18.75
18.4 - 0/13	10 - 17.80/18.60
18.2 - 0/14	15 - 17.80/18.40
18.0 - 0/28	20 - 17.90/18.25
17.8 - 0/40	25 - 17.90/18.25
17.6 - 51/55	30 - 17.85/18.05
17.4 - 66/75	40 - 17.85
17.2 - 81/84	50 - 17.65/17.70
17.0 - 96/105	60 - 17.50
16.8 - 111/116	70 - 17.35/17.45
16.6 - 115/119	80 - 17.20/17.40
16.4 - 123/125	90 - 17.10
16.2 - 127/129	100 - 17.00/17.20
16.0 - 137	110 - 16.85/17.05
15.8 - 147	115 - 16.65
15.6 - 162	120 - 16.55
15.4 - 168	125 - 16.35
15.2 - 183	130 - 16.25/16.30
15.0 - 190	135 - 16.10
14.8 - 196	140 - 15.95/16.10
14.6 - 204	150 - 15.75/15.85
14.4 - 208	160 - 15.60
14.2 - 216/218	170 - 15.30/15.40
14.0 - 227/229	180 - 15.15/15.25
13.8 - 229/234	190 - 15.00
13.6 - 236/241	200 - 14.70/14.75
13.3/13.4 - 243	210 - 14.40
nota bene: at both ends	220 - 14.20
of the joint (L-0 and L-243)	230 - 13.85/13.90
the diameters are measured	235 - 13.55
directly with a caliper	240 - 13.45
	242 - 13.35/13.50

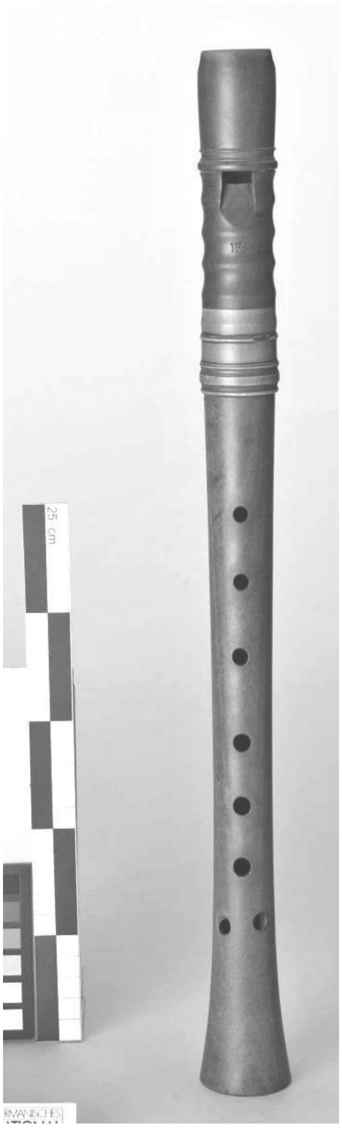
There are small differences between these two sets of measurements. The bore of this middle joint is at the upper end strongly warped (oval in cross section). That is also the section where taking measurements is often tricky: you have to put in your tools in an exactly horizontal position. The photo of the recorder is by the author.

Scanning

A new development in musical instrument research is making CT-scans. The Germanisches Nationalmuseum in Nuremberg is in Germany one of eight research museums and was in the 1970s among the pioneers in using radiography, and also among the first users of three-dimensional computed tomography (3D-CT) for musical instruments (since 1988).



This is a scan of the head of a soprano recorder by Kinsecker (c.1670). The photo was kindly provided by Markus Raquet, who works as restorer of musical instruments in the Germanisches Nationalmuseum. For publication in the FoMRHI-Q, I have increased the contrast of the original photo.



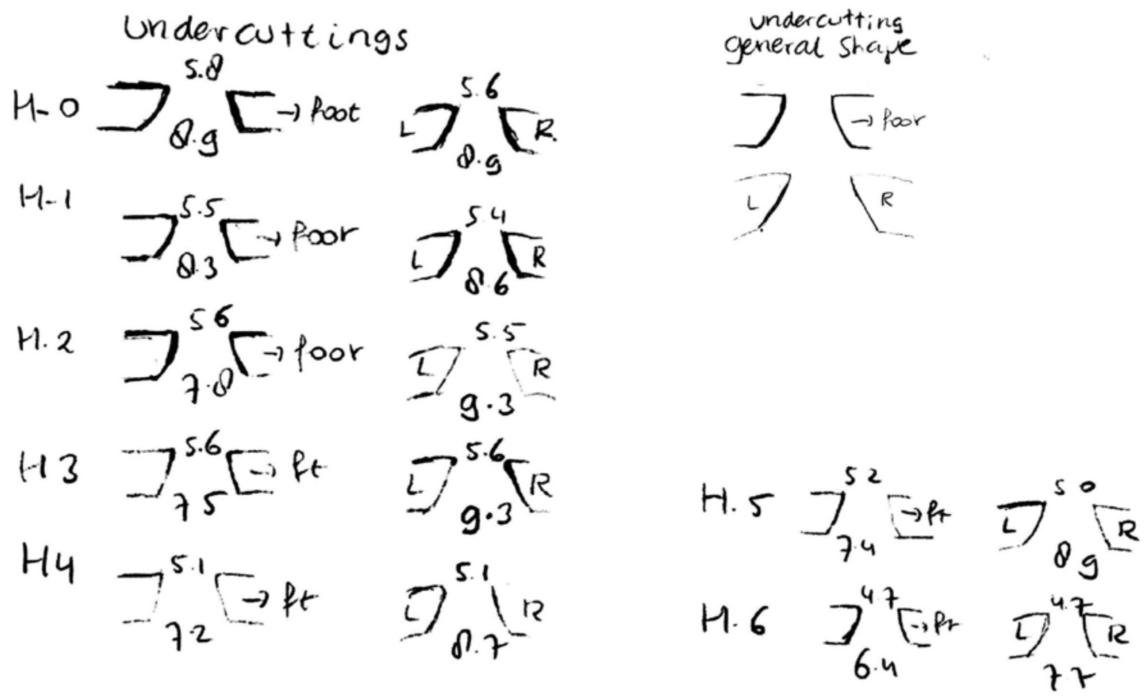
It is possible to extract several dimensions from this photo, but then you must then have at least two reference data, for instance the total length of the head and one or more external diameters. A better technique is working with the original digital files of the scans and use the facilities of a computer program; but that is only possible for who have access to the files and programs. With the best scans, it is possible to achieve an accuracy of about 0.1 mm. But that depends of the quality of the scanning and at the moment only small parts of instruments can be scanned in the highest resolution: the files are so large that special computer equipment is needed to save them.

CT scanning instruments is a nice and ‘contact-free’ (but still expensive) way to measure instruments. But more important is that the scans reveal details which stay hidden from all other research methods. The scan of the Kinsecker recorder shows such details, for instance a hollow space inside the block, which came for the staff of the museum as a complete surprise. There is also some ‘stuff’ visible under the ‘south’ end of the block, which was put there to raise it a little bit.
Interesting is also the course of the grain of the wood (plum wood): the windway must have been made with pushing and not with pulling tools. The horn ring at the right doesn’t fit neatly: some light is visible between the ring and the wood.

Photo right: one of the two (almost identical) soprano recorders by Kinsecker. The photo is downloaded from the website of the museum (http://objektkatalog.gnm.de/objekt/MI100).

Mouth holes and tone holes

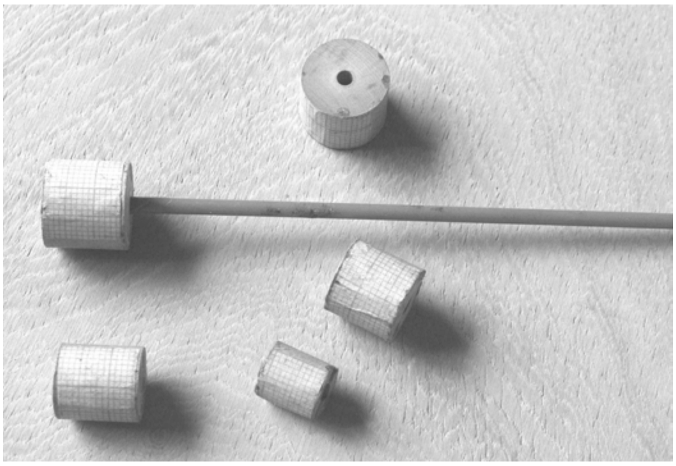
One of the special jobs in examining woodwind instruments is assessing the three-dimensional shapes of mouth holes and tone holes. The point is that on historic instruments these holes are often undercut; these undercuttings can also vary rather a lot.

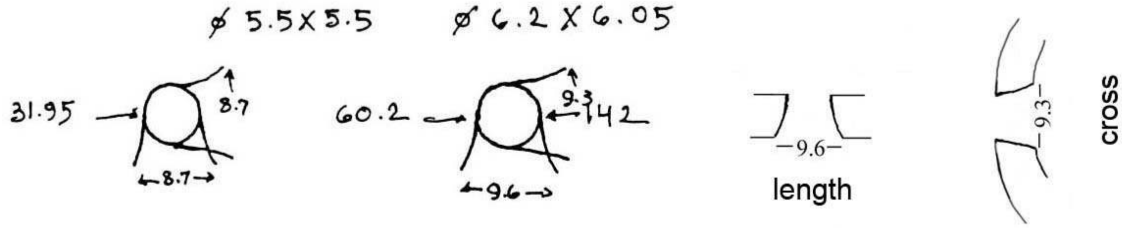


On this picture I have drawn the profiles (in length and cross section) of the undercuttings of the fingerholes of the middle joint of an alto recorder by Engelbert Terton (private collection, Netherlands). It is possible to get this information by using calipers and rulers and looking through the holes. But I had the opportunity to make casts, using dental alginate, This consists of two compounds which must be mixed thoroughly before you put it on a stick through the bore and then push it from below in the hole. It is better before you do that to rinse the surface of the undercutting with a little almond oil: the cast will then (after the alginate has set properly) come off easily. Don't forget to put marks on the casts, for the number of the hole and the direction it was put in. When the transition from the hole to the bore of the instrument is very rounded, it is difficult to give an exact dimension of the maximum size of the undercutting, especially in cross section.

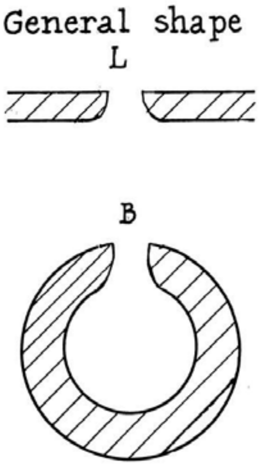
This cast is from the mouth hole of a traverso by Naust (private collection, Netherlands, but stolen some years ago). The arrow points to the lower end (south end of the flute).
The transition from the undercutting of the hole to the wall of the bore is perfectly visible (and not chamfered).

Making casts in museum collections is often not allowed. I made a set of short wooden sticks in several diameters and glued pieces of graph paper on it (photo right). Put these devices in the bore just under a tone hole, and then it is easier to measure the length and width of the undercutting. The accuracy is however not great: not better than 0.5 mm.





We see on this drawing two fingerholes with their profiles, length and cross section combined, such as depicted by Jean-François Beaudin who made many drawings for instrument collections. At the right I have separated both sections for the right fingerhole. Beaudin gave for this instrument the positions of the holes from a reference point to the edge of the holes, and not - what is more commonly done - to the centre.

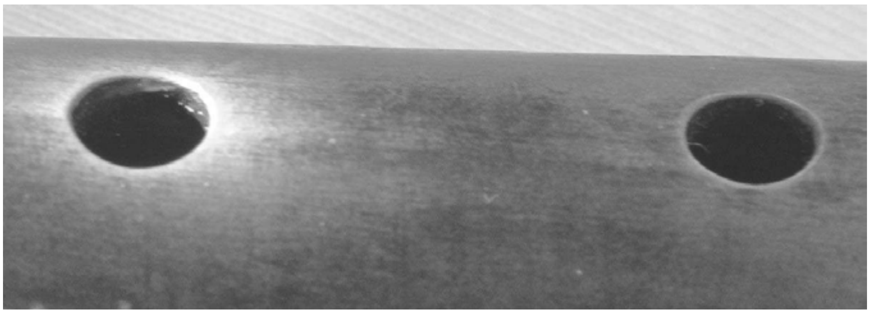


∅ Finger-holes

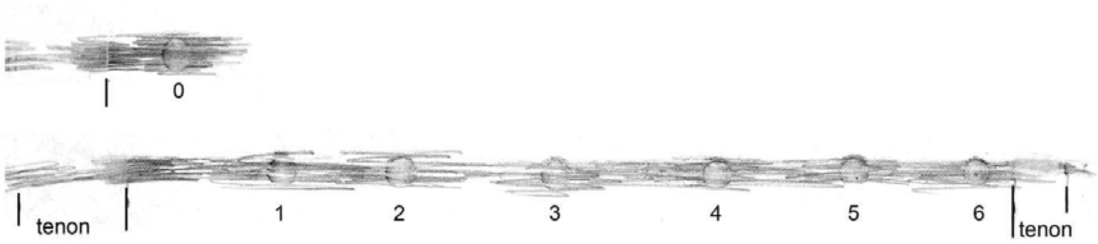
	L × B
0	5,75 × 5,65
1	5,70 × 5,70
2	6,15 × 5,9
3	5,95 × 5,8
4	5,6 × 5,6
5	5,55 × 5,55
6	4,65 × 4,6

Table left: this is the way how Hans Schimmel measured the fingerholes of the alto recorder by Terton (inv. no. Ea 31-x-1952) for the catalogue of Dutch recorders of the 18th century (1991). He didn't give the dimension of the undercuttings inside the bore (he once said to me that these dimensions were not important), but he gave a picture of the 'general shape of the holes'.
The instrument is now back in the Rijksmuseum in Amsterdam (inv. no. BK-NM-11430-94).

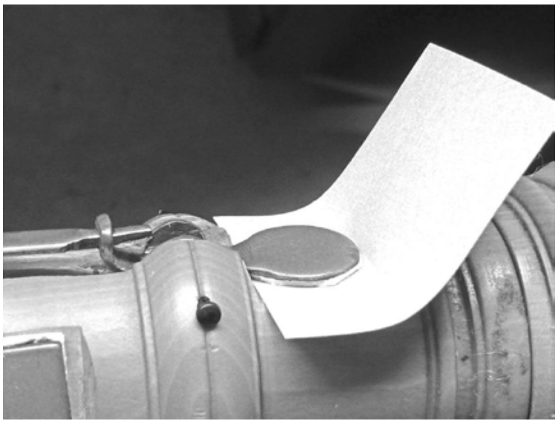
This is a photo of two fingerholes of the same Terton recorder. I shone a light on the left hole: the undercutting is not very marked in the upper section of the hole.



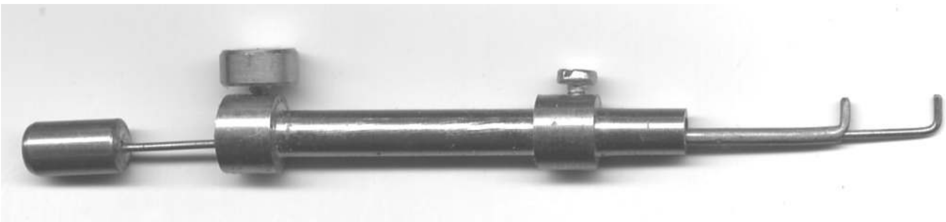
This is an old-fashioned X-ray of the crooked middle joint of the Terton alto (see page 142 of the catalogue mentioned above). The picture is not very sharp, but gives sufficient information about the shape of the undercuttings.



Pencil rubbing doesn't give you information about the interior of the fingerholes, but it is a simple technique which you can do yourself and which give a useful addition to other measurements: it is for instance a check whether you have correctly measured the positions and sizes of the holes. Misreadings happen sometimes and that is one of the reasons why I always give the advice to make drawings on a 1: 1 scale, and also to make your own version of a drawing when you use measurements from other people.

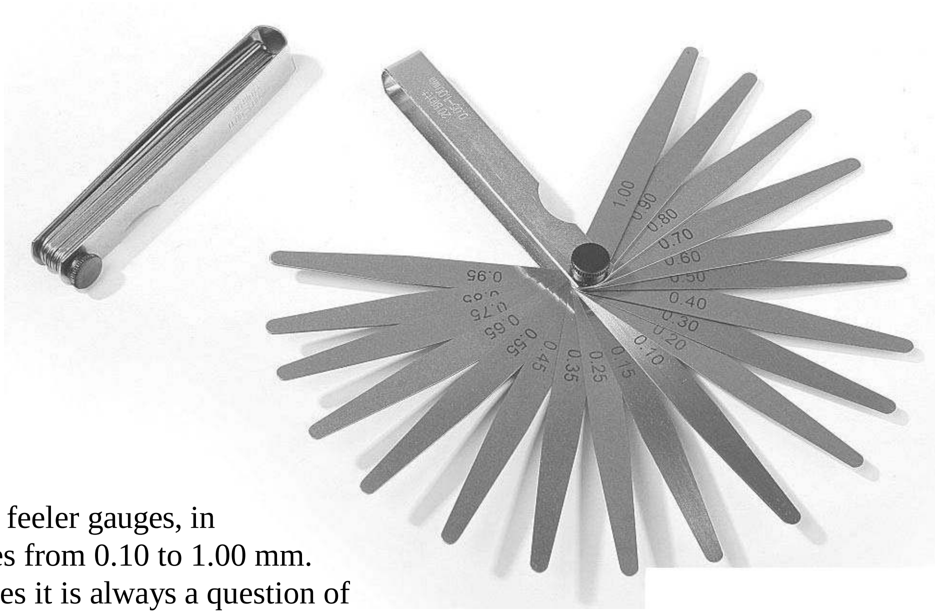


Key holes are sometimes difficult to measure, because they are covered by a part of the key which cannot be removed. What you can do then is put a piece of (soft) paper under the key (left photo), and press hard on the key. The result (right photo) is not unlike what you see with pencil rubbing.



The tool on this photo (made by Jos Everts) is maybe helpful to measure undercuttings of holes, but I doubt if it may be used in museums.

Other tools and measurements



This is a set of feeler gauges, in millimeter sizes from 0.10 to 1.00 mm. With this gauges it is always a question of comparing thicknesses, for instance of the edge of the labium of recorders. This is not an easy technique, as I can tell you from comparing the results by different people measuring the same instrument.

This is an inspection camera: the tube with the lens has a diameter of only 9 mm and has 4 small LED lights. The flexible cable is one meter long. The system has a USB connection and you can make photos and videos. See http://lemato.nl/product/hbm-inspectiecamera-model-5/ for more details (in Dutch language; HBM doesn’t export their products to other countries).
I do not have this inspection camera myself, but I saw David Rachor (a bassoon expert from the USA) working with a similar device. The lens has a very wide angle, so you must really learn to interpret the images. But the price of the camera on the photo is low (about 100 Euros).