

De Machinis Musicis

Of Musical Machines · the bowed keyboard, the drum of cams, and the reckoning of a player of brass

1. VIOLA ORGANISTA

The bowed keyboard — an endless bow of horsehair

The harpsichord plucks and the sound dies at once; the viol sustains but sounds one voice, or two with labour. Therefore let a loop of hair, rosined, run continually over wheels turned by a treadle, and let each key press its string down upon the moving band. Then a man alone may hold six voices as long as his foot endures, and swell each by the weight of his finger.

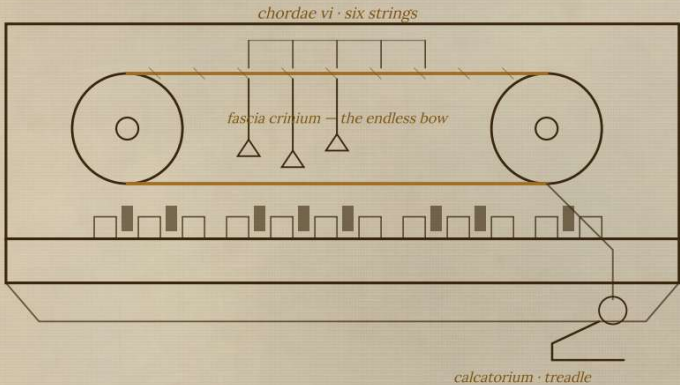


Fig. 1. Plan of the viola organista: two rosined wheels carry a band of horsehair beneath the strings; the key lifts its string into the band, and the treadle at the right keeps the band in motion.

PARS	MENSURA	MATERIA
Rota maior <i>drive wheel</i>	240 mm	walnut
Fascia <i>hair band</i>	1420 mm	horsehair
Velocitas <i>band speed</i>	1.9 m/s	—
Claves <i>keys</i>	45	boxwood
Ambitus <i>compass</i>	C–a	—

2. ORGANUM CHARTACEUM

The paper organ — a portative that folds

Pipes of tin are heavy and dear; pipes of stiffened paper, gummed and dried upon a wooden mandrel, weigh a twentieth and sound near as well in the treble, though the bass mutters. Let them be set in a chest of poplar with a bellows worked by the left elbow, so that a man may carry the whole upon his back and play in a garden.

PARS	NUMERUS	PONDUS	MATERIA
Fistulae <i>pipes</i>	61	2.4 kg	paper
Arca <i>windchest</i>	1	4.1	poplar
Folles <i>bellows</i>	2	1.8	leather
Claves	30	0.6	boxwood
Summa <i>whole</i>	—	8.9 kg	—

An organ of tin in the same compass weighs sixty kilogrammes and needs two men and a cart. *Coniectura: paper fears the rain and the mouse, and the bass mutters because a soft wall drinks the sound it should return. Both faults are one fault: I have built a body too kind to be loud.*

3. TIBIA CHROMATICA

The sliding recorder — a pipe that will not step

Rather than pierce the pipe with holes, let it be made in two sleeves, the inner drawn out by the left hand as a trombone is drawn. Then the voice does not step but slides, as the human voice slides in grief, and no note is forbidden. Six holes give nine tones and a great deal of arithmetic; the sleeve gives all of them and the ones between, and asks nothing but a steady arm.

EXTRACTIO	LONGITUDO	VOX
Clausa <i>shut</i>	325 mm	c
Uncia i	344	b
Unciae ii	364	bb
Unciae iv	409	ab
Unciae vi	459	g
Aperta tota	650	c

An octave costs the doubling of the pipe, therefore the sleeve must draw out its own length — three hundred and twenty-five millimetres, which is further than an arm can reach while the mouth stays upon the mouthpiece. *Coniectura: fold the sleeve back upon itself in the manner of a trumpet and the reach is halved. I have drawn this three times and each time the water gathers at the fold and the instrument gargles. The problem is not the number; it is the spit.*

4. TYMPANUM MECHANICUM

The drum of cams — a rhythm written upon a cylinder

Set pegs of iron into a barrel and let the barrel turn once in the length of the measure. Each peg, passing, lifts a hammer. Move the pegs and the rhythm is changed; nothing is written and nothing forgotten. Two barrels of unlike girth, geared three to two, will beat three against two for ever without quarrelling — which no two drummers can do.

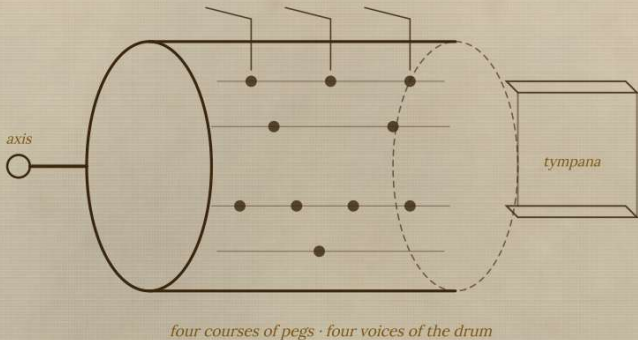


Fig. 2. The barrel of pegs. Above, three hammers of the first course; at the right, the two drums it strikes. *Coniectura: whoever can write a rhythm in iron can write a melody in iron, and then the instrument plays the absent man.*

5. RATIO MACHINARUM

Reckoning of the gears, that three may sound against two

PROPORTIO	DENTES	REDIT	FIGURA
Aequalis 1:1	24:24	1	unison
Duplex 2:1	24:12	2	octave
Sesquialtera 3:2	24:16	6	fifth
Sesquitertia 4:3	24:18	12	fourth
Sesquiquarta 5:4	30:24	20	third

Redit is the number of turns after which both wheels stand again as they began: the same number that the ear waits through before it hears the pattern close. The sweet intervals return soonest. *Here mechanics and music are not two arts but one art seen from two rooms.*

6. DE TACTU CLAVIS

Of the touch of the key, which no drawing can hold

The plucking keyboard gives one loudness only, for the quill either lifts the string or does not. The bowed keyboard gives all loudnesses, for the finger's weight decides how hard the string is pressed into the moving hair. Therefore this instrument alone among keyboards has a voice that can grow within a held note, as a singer swells upon a long vowel.

TACTUS	PONDUS	VIS SONI	EFFECTUS
Levisimus <i>feather</i>	18 g	1	a whisper
Levis	40	2.2	piano
Medius	85	4.6	the singing tone
Gravis	150	7.9	forte
Nimius <i>too much</i>	240	8.1	a scraping

Beyond a hundred and fifty grammes the string is crushed into the hair and the tone breaks into a grinding: the instrument has a ceiling, and the player must learn where it is as a rider learns a horse's mouth. *Coniectura: I have given the machine a nerve. It is the first of my devices that can be played badly, and I count that a proof of its life.*

7. DE AUTOMATO

Of the automaton, and whether it may be said to play

Set the barrel of pegs to work the keys of the paper organ and the bellows to a falling weight, and the machine will play a piece without a man in the room. I have seen the water-organs of the Villa d'Este described and I do not doubt them. The question that keeps me at this leaf is not whether it can be done but what has been done when it is done.

For the barrel does not hurry at the sad line nor lean upon the high note; it performs the piece as a mill grinds corn, faithfully and without opinion. Set it beside a boy of twelve who plays the same notes badly and every listener in the room will turn to the boy. *Coniectura: what the ear wants is not the notes but the evidence of a choosing mind — the small delay before the difficult interval, the pressure that says the player knows what is coming. I can build a machine that plays. I cannot build one that has known the piece for a week and dreaded this bar since Tuesday, and until I can, the boy is safe.*

LIRA ARGENTEA

The silver lyre in the shape of a horse's skull

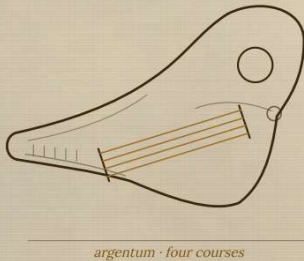


Fig. 3. The lyre in the form of a horse's skull, beaten in silver, with four courses stretched from the jaw to the crown.

Carried to Milan in 1482 as a gift and a proof. The skull is chosen because the bone rings where the wood mutters, and because a courtier remembers a horse where he forgets a box.

AD MARGINEM

In the margin, in red chalk

ἡ μηχανὴ οὐ τρεῖς ἀνθρώπων ἔργον

The instrument does not tire. Therefore give the instrument the labour and the man the invention.

TIBIA CHROMATICA

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ROTAE ET DENTES

Teeth of the wheels that turn the drum of cams

ROTA	DENTES	VICES
Prima, hand crank	12	1
Secunda	36	3
Tertia	48	12
Drum wheel	96	48
Bow wheel	24	½
Escape	8	—

The whole song is nailed into the drum as pins. Change the drum and the machine forgets one air and learns another; the wheels need not know what they play.

IMPENSA MACHINAE

What the thing would cost, reckoned in soldi

MATERIA	PONDUS	SOLDI
Oak, seasoned	40 lb	36
Brass, wheels	9 lb	120
Iron pins, 400	2 lb	48
Horsehair, bow	—	14
Gut strings, xx	—	30
Glue, wax, oil	—	8

Two hundred fifty six soldi and the labour of a joiner for a month. Less than a horse, and it does not eat. *Coniectura: the Duke will ask for two.*

«Mechanics is the paradise of the mathematical sciences, because here one comes to the fruits of mathematics.»

Of the three machines on this leaf, the lyre was made in silver and given away, the bowed keyboard was made in wood and is in the inventory of 1499, and the paper organ exists only here. *Two of three is a good rate for any workshop.*