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PERPETUAL ELECTROMOTIVE OF GIUSEPPE ZAMBONI. MANUFACTURE, COMPARISONS AND DEVELOPS

During a cold morning at the end of the winter of 1812 abbot Giuseppe Zamboni gave to Veronese typographer Dionigio Ramanzini a manuscripts titled "Della pila elettrica a secco. Dissertazione", then two years later the typography Mainardi published his second work, "Descrizione ed uso dell'elettromotore perpetuo". These dates mark the first appearance in scientific literary of a brilliant experimenter that perfected his electrical machines with much meticulousness for following thirty years. Between 1820 and 1822 the heirs Merlo published the fundamental treatise in two great volumes with the title "L'elettromotore perpetuo", in which Zamboni developed and deepened the method to build and for the theoretical and experimental functioning of the instruments that he realized since 1810. We can say that this date marks the birth of the Zamboni dry piles and later the set-up of the first electrostatic clock: practically an electrical machine that was the starting point for the history of the finalized applications of the electricity, at least in Italy.

With these preliminary statements I expected to find in Verona many evidences or biographical and monumental references to remember one of the most stimulating and active minds in this city. Instead few years after his death Giuseppe Zamboni seems to disappear from the cultural panorama of Verona. Today there is only a memorial tablet on the front of a building where he lived and that now belongs to the bishop, a marble bust in the entrance-hall of the Agriculture Science and Letters Academy in Verona, that has its seat in Erbisti Building, piece of the sculptor Grazioso Spazzi, in addition to a pair of portraits, one of this in the Academy and the other in the Liceo Classico Scipione Maffei in Verona. And yet his long career of teacher was characterized by an inexhausted experimental work that represented a chapter rich of appreciations.

Of course the history of sciences is growth around the great ideas and therefore hinged on the great personalities that were able to make sprint forward the human thought with decisive and conclusive propositions. But if Volta, Faraday, Maxwell, Einstein were able to catch a powerful synthesis we have not to neglect those people that worked in shadow but that prepared the ground with a work of useful tests, sometimes with experiments without immediate results but providing an apparatus that, either baited new answers at unsatisfactory theories, or directed one's step towards new horizons. And an interesting ground where to search is just that one of Italian province in which not secondary actors experimented, theorized, produced, so it seems right to recover and to bring them out.

1. Biographical outlines

Before sketching some biographical elements we have to mention the atmosphere and the ambient that characterized the Veronese cultural panorama, that for the 19th century are not yet deepened in all their aspects. In fact, while the personalities of arts, literature and economy are well known and studied, in the scientific area the names of the most illustrious researchers are heritage only for a few expert people. Instead Verona has had a tradition since 1500 as a lively city with the presence of personalities that produced important works in various scientific fields: from Botany to Zoology, from Physics to Geology, from Archeology to Mineralogy, from Mathematics to Astronomy.

Then in which political atmosphere did the study of this physics "electrician" born? The historical period is difficult because Verona was the crossroad of the Napoleonic campaign and of the Austrian war replay. After the occupation of the French troops of Napoleon Bonaparte in 1801, some important historical events happened: there were some encounters Austria and France made peace of Lunéville, with which the frontier of Cisalpine Republic wanted by Napoleon was restored in coincidence with the river Adige in the reach of Venetian land and farther Badia Polesine. So Verona was divided politically into two parts and oppressed by two different dominates, a situation lasted till the conclusion of third coalition in 1805, when the Italy kingdom was proclaimed with Napoleon as aking, and viceroy Eugène Beauharnais. On the frontier of Italian Republic (ex Cisalpine) the French general Massena attacked the Austrian army commanded by Archduke Charles of Asburgo who was beaten. Massena arrived to Verona on the left bank of Adige driving away the Austrian and eating definitively in Caldiero. Napoleon, with the peace of Presburgo, required also Venice, the Istria and Dalmatia, so Verona returned under an only government. After less than 10 years, in 1814, the heavy defeats of the wars of Russia and Germany overcame the Italic kingdom and in Verona arrived the Austrian troops that governed the city fortifying it solidly, till 1848.

Fig. 1 Portrait of Giuseppe Zamboni in an engraving.

So in a period rich of unrests Giuseppe was born in Arbizzano (a few kilometres from Verona) son of Luigi Zamboni and Caterina Rensi: it was June 1776, one year later Alessandro Volta realized the perpetual electrophore. Zamboni was under way to the philosophical and theological studies, as usual in that period, because the seminary satisfied the vocations but for many people it was the way that took to a sure cultural education. In this period of formation emerged his lively and precocious brains so he completed the studies in advance, one year before the end assigned by canon laws, and became a priest in 1800. The next year, when he was only 25, he was trusted the teaching work of Logic and Metaphysics in the municipal school, or Ginnasio Civico Repubblicano of S. Sebastiano (today seat of the Civic Library keeping his manuscripts), that was considered the local university. Thanks to raid develop of his affairs in physics, and particularly for the electric phenomena, in 1805 he was assigned professor of Experimental Physics and Applied Mathematics at Royal Departmental College, later the present Ginnasio e Liceo Classico "Scipione Maffei", where for 45 years he practised a passionate and appreciated teaching (besides taking care of the laboratory where he could experiment his electrical machines for a long time), also because the teaching post was confirmed with the royal Napoleonic decree of 17th December 1817, that defined the situation of the present College.

His scientific life was characterized by two main periods: the first starting from the years 1810-1815, in which he developed his first instruments reaching the fame, the second period from 1830, in which he worked consolidating his position and improving his researches about dry piles and electrostatic systems (exceeded then by those electromagnetic ones).

In the first period of his teaching he developed his true passion, the physics, and the curiosity induced him to autodidactic research in the experimental field: so the physical sciences prevailed over humanities and theological doctrines. The announcement of Voltàs pile made to explode a new frenzy in many researchers, as Zamboni who probably could use the first instruments, for electrical experiments, given before to the College by count John Baptist Gazzola, who had constituted his personal collection of physical instruments. During the morning he treated mathematical and physical lessons being able to involve the students in news of electrical and magnetic studies, making to experiment them the new instruments. Then in the afternoon he could dedicate himself at his researches. The principal objective was the construction of a pile with qualities superior to Voltàs pile, that deteriorated rapidly, the so-called dry piles (however the terminology is not to confuse with that one defining the modern batteries where the electrolyte is in the gel state or stored in a porous membrane). His preparation was supported by a valid experimental practice, by a technical ability to project that was fundamental in the develop of his next works, in addition to inexhaust observation of produced phenomena. Many of his articles were published on the memories of various academic institutions during the 19th century, as in Annali delle Scienze del Regno Lombardo-Veneto, in Memorie della Società Italiana delle Scienze di Modena, in Memorie dell'Imperial Regio Istituto Veneto di Scienze Lettere ed Arti, in Memorie dell'Accademia di Agricoltura Commercio ed Arti di Verona (today Accademia di Agricoltura Scienze e Lettere).

His life was spangled by some trips in Italy and in Europe: Metternich [Winneburg Klemens Wenzel Lothar Prince of (1773-1859)] invited the physician to Vienna in February 1817, where he introduced the electromotive to emperor Francis I that gave him rich snuff-boxes. He passed by Rome and Naples where he met Piazzi, visited some Italian laboratories and met Volta, Ruffini and Venturoli. In 1822 he went to Paris and in 1824 to London: he was received by the members of the French Academy and he showed his machines to French Institut. This one was the great occasion to settle contacts with Arago, Ampére, Fresnel, von Humboldt, Biot, Cuvier, Brewster, Wollaston, Faraday: he had epistolary and scientific exchanges (two letters by August De La Rive are kept in the Civic Library of Verona), as well as many compliments. He could buy some new machines at the physics laboratory in Paris with which he improved the devices of his scholastic laboratory. In fact already in 1804 he went to Milan where he saw a rich collection of English machines that he found very useful for his laboratory. So when he returned to Verona he made them buy by the District Counsel for 11.000 Milanese lire, a capital that was an enormous sum for that period. He had dedicated all his money and energies at the laboratory so that to endow it technically in a way very substantial and he could be in competition and excel in front of any institution in Italy, only exceeded by the laboratories of a couple of Italian kingdom universities. Then he left his Klarke's magneto-electrical machine and two great electrical clocks, besides the books of his scientific library in heritage to school.

The perfecting and the precision of his clocks was performed in the last years too. Zamboni died on 25 July 1846, probably after some premonitory heart attacks. Maggi (1851) wrote about this event: "... while he was in conversation or teaching among the young people, suddenly, two or three very violent darting palpitations, if he felt his heart sink tight ..."). Death arrived after he gave his last announce to the scientific ambient of his further realization. His very near collaborator Gaetano Spandri was the only witness of such ideas, because during the last years he helped Zamboni in the experiments.

Thanks to the acquired fame with his "perpetual clocks" he was elected to membership, with related certificate, in some academies as the Società Italiana delle Scienze already in Modena (6 April 1820), the I.R. Istituto Veneto as effective member to pension, the Royal Academy of Monaco, the Reale Istituto d'incoraggiamento alle Scienze Naturali of Naples (9 march 1820), l'Imperiale e Reale Società Aretina di Scienze Lettere ed Arti (29 July 1821), the Reale Accademia delle Scienze of Milan, the Accademia delle Scienze dell'Istituto di Bologna (3 October 1837), the Accademia di Scienze Lettere ed Arti of Padua (15 may 1843), the Accademia degli Agiati of Rovereto (23 April 1813), the Ateneo of Venice (6 march 1839) and of Brescia (3 june 1819), the Accademia di Scienze Lettere ed Arti of Bergamo (11 January 1844), the Accademia scientifico-letteraria dei Concordi of Rovigo (27 April 1840), the Società Economico-agraria of Perugia (3 April 1840), the Accademia di Agricoltura Commercio ed Arti di Verona as a member of the commission entrusted to examine the effectiveness of the technical and scientific news produced in Verona and proposed to the Academy.

Of course he never forget his sacerdotal mission, he elaborated some texts about theological subjects, while the bishopic acknowledged a particular preparation, a great ability of wisdom and a deepened theological study, so he was nominated a "prosinodale" examiner, that is to be a member of those ones who interrogated the priests applying for the Paris churches and in Episcopal College, and that defined the controversies about the moral (in the cases of coscience) and the liturgical precept, as well as general promoter of the Pious Work of Christian Doctrine.

2. THE PILE AND VOLTIAN REVOLUTION

Until 1800 the production of electrical phenomena was linked essentially to the effects derived from the rubbing of different insulating substances. The age of amber sticks and of electroscopes with small balls of elder had passed by now, but the price of the newness consisted of a use of giant electrostatic machines, as those ones by Van Marum and Cuthberston still kept in Dutch Museums. Revolving vortically they produced voltages of 100.000 volts, jump sparks long an half meter and charged Leyden bottles, that is rudimental condensers able to kill a man, as sometimes happened during the experiments. But they were not very practical and cumbersome systems that didn't facilitate the idea of a concrete use of electricity out of laboratories.

In this historical moment an Italian physics announced a series of electrical phenomena huge for many points of view, generated with the simple help of a glass of water and two little thin metallic plates. In fact, according to Alessandro Volta, the electricity would develop with the contact copper-zinc, while the contacts zinc-acid and acid-copper would be helpful for its transport. The Voltàs announcement produced and incredible flourishing of investigations about relations existing among franklinian, animal and voltaic electricity, besides the dynamics of the chemical phenomena produced by galvanism.

It was a great step forward, so much so that Davy "in 1810 considered the Voltàs battery as the call for all european experimenters, the instrument that had enabled impressive discoveries" (Abbri e Torracca, 1988), but the theory that was developing had some defects besides the disadvantages that happened in the Voltàs piles. Meanwhile, the zinc consumed under the action of sulphuric acid, either the pile supplied current or not, and this one was an annoying an further sacrifice. If instead the acid was not put in water, the pile supplied a smaller current and in a very short time it was subject to a second disadvantage, that however appeared before or after: the polarization. After a period of operation, that could last minutes or hours, in function of supplied current, the pile stopped operating until the fluid was not mixing and the electrodes cleaned with careful.

Clearly the zinc sulphate formed near the negative pole, but it was a very soluble salt, what trouble could it give? Instead on the positive pole it developed hydrogen that, in addition to be insulating, melting in water, produced an inverse tension that stopped the pile. These phenomena were not understood immediately, but the inventors devised some methods to avoid the difficulties, at about the middle of the 19th century.

The first method was the direct attack, or of brute force: to avoid that the pile operation produced chemical modifications near poles. It was not easy. The most elementary approach was realized by Daniell: the zinc was bathed in zinc sulphate, the copper in copper sulphate; the two solutions were separated with various devices. It worked well, supplied a constant tension, but because of impurities the zinc consumed with the inactive pile too. However Daniell's pile had a long life in telegraphic stations.

The second method, still much used, was more refined. It consisted to interpose a strongly oxidative substance, which prevented the formation of hydrogen and the consequent polarization, between the electrolite and the positive pole. The prototype of this type of piles was invented by Leclanché in 1868. In this pile the negative electrode is of zinc, the electrolite is a paste of ammonium chloride, while a layer of manganese dioxide (pyrolusite or "soap of the glasses", MnO_2) surrounds the coal positive electrode, cheaper than copper.

Then a partial alternative was invented in the first years of 19th century by de Luc and Zamboni that avoided the obstacle of chemical aggression with their "dry piles" which were based on the exclusion of traditional "humid" chemical substance and used simple sheets of paper and a little humidity in the atmosphere.

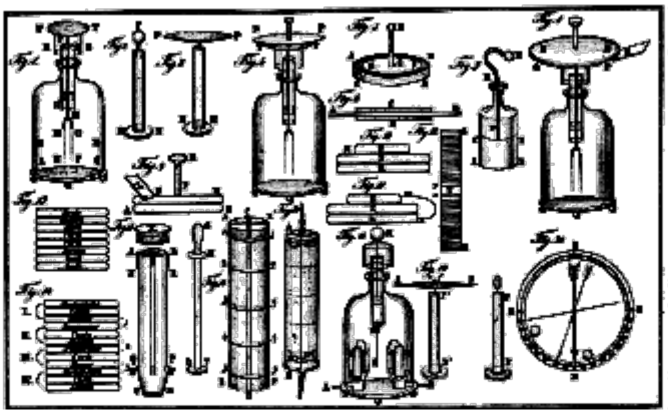

Fig. 2 Instruments for the construction of piles realized by Giuseppe Zamboni, drawn from "L'Elettromotore perpetuo. Istruzione teorico pratica", table 2.

In any case the problem of isolation of piles was still to be solved effectively. Apart the amber, the mica, the quartz, the sulphur, fragile or expensive, there were not many good insulatings: the glass was already sufficient, but it had the very bad property to absorb water and smog on the surface, losing the insulating properties. It was possible to avoid the disadvantage painting the glass with shellac (common paint with alcohol of furniture-makers) but the expedient was short lasting. However machines and accessories treated in this manner are till kept, above all machines realized during the second half of the 19th century, when the shellac was available at a high purity degree. Between the end of the 18th and the beginning of the 19th century they preferred to resort at the covering of glass with a layer of hot sealing wax. And because the sealing wax had red colour, because of the minio entering its composition, the insulating electrode of electrostatic machines was characterized by showy supports red coloured.

These practical realizations lead the theoretical understanding of the working of the pile.

3. PILES AND PENDULUMS, OR PERPETUAL ELECTROMOTIVE

Some models of electrostatic time-keepings were realized already in 1809 by De Luc who planned a new source of static electricity that was known as the De Luc's column. The columns were the result of the attempt to discover the source of electrical energy in the Voltàs pile. The results of his experiments were shared at the Royal Society, but for some reasons they were not published in the "Philosophical Transactions", so De Luc widened his reasoning and achieved new results, as shown by an article published in two parts in the Nicholson's Journal in the issue of October-November 1810.

In the same period also Zamboni autonomously realized that "la colonna voltiana infatti, per l'ossidamento de' due metalli bagnati dalla soluzione acida e salsa, portava seco il germe della propria sua distruzione. Conduttore solido non poteva mettersi in luogo dell'acqua, che la sua forza elettromotrice avrebbe guastato: ciò appunto diceano espresso i principi teorici e gli studi sperimentali del Volta. Ma fra i corpi che, per contenere in sé alcuna traccia di umidità, danno qualche passaggio al flusso elettrico senza tuttavia nuocere ai metalli, era bene e non forse indarno cercare. E la tensione intanto (uscita quasi altrui di vista per la sua tenuità) non avrebbe potuto, pel men perfetto ufficio del conduttore, farsi a più doppi ingrandire sino a trarne qualche nuovo utile effetto?".

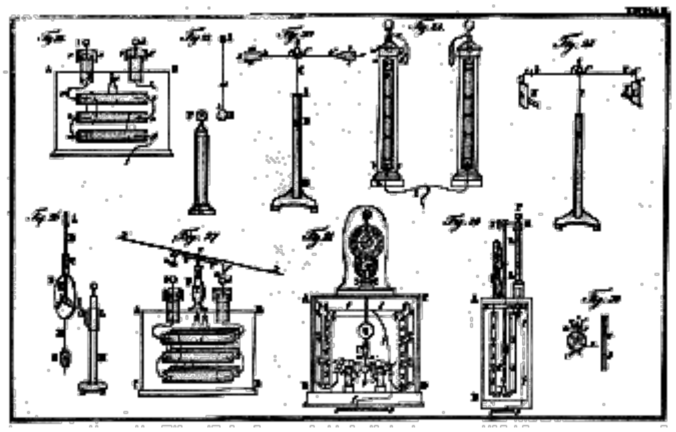

Fig. 3 Structural arrangements of electric clock and "perpetual" electromotive realized by Zamboni, drawn from "Istruzione teorico pratica", table 2.

Since 1810 the attention of Zamboni was wholly captured by the construction of a pile with qualities superior to Voltàs piles. The originality of his ideas must be seen in this direction because his most interesting theoretical and experimental realization, was the elaboration, the construction and the practical application of the so-called "dry" piles. An interesting characteristic was the small dimension in which he was able to crowd thousands of electromotive couples to increase the produced tension. So he realized also some instruments to build the piles in the defined shape and to box them with more suitable sealing.

The piles called "dry", were constructed with materials that the abbot thought the best to obtain electromotive effects without the apparent presence of a chemical process, which slowly modify the metals and degrade the performance of pile. So he eliminated the acid and corrosive fluid that caused the wear of the component metals. Really they operated thanks to the humidity present in the air, sufficient for the conductivity between different metals (Zamboni had not understood this aspect and even fully the principle of working). In fact in Zamboni pile the electrolite was present: it was the small stock of greasy acids contained in organic substances with which the author coated with parsimony the small metallic layers that with thousands pairs constituted the pile.

These piles were better than those ones of De Luc, and also other sets were judged by the scientific community superior to the instruments realized by his colleagues. All scientists of that period agreed to believe casual the convergence of the researches of two physicians.

Every pile was formed by 2.000 discs or more, realized with foils in trade paper called "silver paper" (on this paper was spread a thin layer of tin or an alloy of copper and zinc called "tombacco") and on its metallic surface was spread a pulp composed by pulverized charcoal, and kneaded with water or worked with nitric acid. When Zamboni realized his first piles and simple pendulums he wrote to Alessandro Volta two letters at least already in 1812 to present him the results of his work. Volta answered with two letters, in the September of the same year suggesting that the "manganese nero di ottima qualità supera di assai nella facoltà elettromotrice e la piombaggine e il miglior carbone" (for requirement of quality, Giuseppe Zamboni provided the manganese dioxide from the near by caves of Alcenago in Valpantena and of Torbe in Valpolicella where there were the mines "Buso del ferro" of Novare, "Siresol" in territory of Negrar, "Crocetta" of Marano). Of course the idea to eliminate chemical substances that deteriorated the metallic pair was not new; in fact it was tried by Volta himself, by J.W. Ritter, Biot (who used as conductor the potassium nitrate), by G.B. Behrens (with copper, zinc and gold paper), in 1803 by Hachette, Desormes (simple pair of zinc and copper separated by paste) and in 1809 De Luc (with zinc, silver and wetting paper).

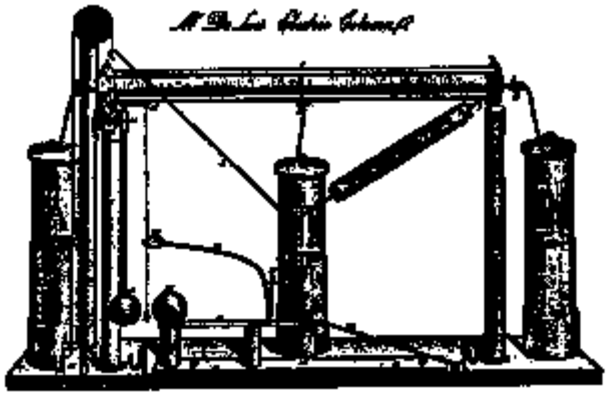

Fig. 4 Electric column and air electroscopy of De Luc.

Further to suggestions of Volta and after having experimented the use of zinc sulphate pulverized and dissolved in water Zamboni passed to black and friable manganese dioxide diluted in water with addition of a little of paste. In fact the principal problem was constituted by the fixing of manganese dioxide that was made to adhere on discs also with greasy substance, or mixture alloied with rape oil, milk or honey: then the mixtures were eventually suspended in a very concentrated solution of zinc sulphate. The discs were inserted, laid in a glass tube internally and externally painted with insulating rubber. After many tests he established that the very common paper worked very well. The contained humidity was sufficient to let the electricity cross. The scarce quantity of humidity and the adhesion of particles to the soaked paper didn't permit to corrode the metals during very long times. Moreover the thin layer of produced dioxide protected against an ulterior oxidation. The control of piles was not a secondary factor, but the experimental carrier line, because it was necessary to evaluate their behaviour during the time and their sensibility to the local atmospheric condition.

The pile was then covered with fused colophony (or Greek pitch, a resin so called from Colophon and it was a solid residual of preparation of oil of turpentine), than plastered with virgin wax, that did not absorb the humidity of papers during time, and finally covered with two or three layers of insulation paint. The principal problem of these piles, that makes the construction difficult is caused by the employment of original materials used as cohesion elements of manganese oxide.

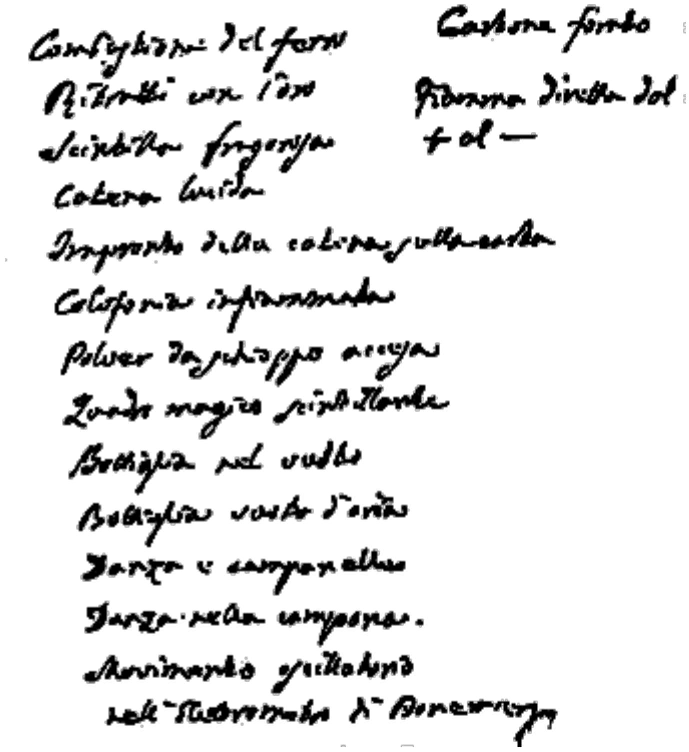

Fig. 5 Zamboni's autograph kept at the Liceo Classico Virgilio in Mantua, with a list of materials used to construct the piles.

The problem of the columns' insulating had already been observed by Alessandro Volta, and it made unstable the effects of electric production, so much so that he wrote to Zamboni: "Tali effetti complicati nelle varie circostanze è impossibile calcolarli esattamente, però si possono con facilità valutare all'ingrosso; e a rilevare quanto influisca vantaggiosamente l'umido dei bollettini cartacei, o simili, basta tenere la pila per uno o due giorni in luogo umido, ed esplorarla poi in un luogo e giorno convenientemente asciutto; siccome a rilevare l'influenza nociva dell'umido esterno, basta indurvi a bella posta tale umidità superficiale; che se infine procurisi l'umido maggiore a detti bollettini, nel modo indicato, o altrimenti, e allo stesso tempo la maggior secchezza all'esterna superficie della pila, con esporla e.g. per brev'ora a un'aura di fuoco, o a raggi del sole, si otterrà tutto quel vigore e prontezza di segni elettrici, ch'atta a dare cotal pila, che non è a rigore, ma può ancora denominarsi pila a secco".

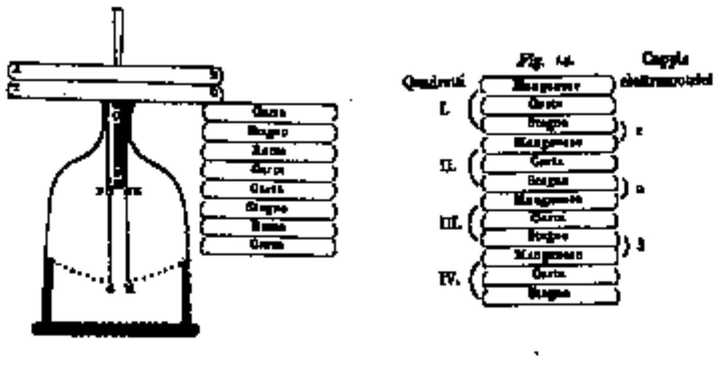

Fig. 6 Copper and zinc pairs with electrometer (left) and electromotive pairs tin manganese (right), drawn from "L'Elettromotore perpetuo" di G. Zamboni, vol 2 p. 39 and 65

But Volta appreciated the solutions adopted by Zamboni, as he wrote in a letter to him: "... ma a più gradi degli elettrometri applicati immediatamente all'uno e all'altro polo, le notabili vicende e alternative a cui soggiacciono esse tensioni, indicate da essi elettrometri; e soprattutto le quasi perpetue oscillazioni de' pendolini adattati alla maniera di De Luc, e le realmente perpetue dell'ago calamitato adattato alla maniera sua, prestantissimo signor Professore, nella molto più bella, comoda, ed elegante macchinetta da Lei così bene immaginata e descritta, che mi piace al sommo e non posso finir di lodare".

These piles produced a potential difference of some thousands volts and current about microampére. The constructive system guarantied the working for very long period thanks to a very slow polarization. This very inviting characteristic of dry piles gave exceptional performances as with short stops of their use they had a partial recharge with the capture of atmospheric humidity. In fact in a second time the Veronese physician understood that he had not to isolate the piles completely but that it was necessary a hole of communication with the external ambient. To confirm this characteristic Zamboni himself wrote that some of his pendulums were in function during many years without stopping. Besides a couple of piles started on 18 May of 1839 at Modena Physics Institute worked almost non-stop for almost 100 years. (Pierucci, 1933). This perpetual electromotive consists of a little and very light pendulum pivoted on an axis moving between two platinum electrodes distant about 3 cm each other and linked to the piles. The pendulum is constituted by a platinum thread long about 10 cm and by two concentric metallic rings connected rigidly together with in the enter a very light axis staying on two horizontal supports of quartz. The control of working of pendulum during time had underlined a slow variation of its velocity: in 1839 it made 95 (simple) oscillations in one minute, in 1843 it made 92,5, in 1846 the oscillations were 80,6. In 1847 it was found motionless, so it was restarted and already in 1855 it made 91 oscillations in one minute, that were decreased to 89 in 1861. At the control in February 1932 physicians measured 46 oscillations but after a period of rest in June of the same year the instrument it had increased to 60 oscillations. Another testimony comes from professor Palmieri, inventor of bifilar electrometer, who had possessed a Zamboni pile and he affirmed that it had worked for more than 40 years.

Unfortunately these electric pendulums had to be treated with care to maintain efficient the effect of the piles, and not all those ones that had acquired them were satisfied, because of their inexperience. To maintain efficacy the piles we know from Zamboni himself in a letter sent to prof. Santi Linari living in Siena in 1833, that was used to clean the little discs and superior ring at least once a year, using paper soaked of alcohol; because he knew that a certain oxidation was produced in the time; moreover he recommended to clean also the oxidation that formed in the points of braces of pivot of pendulum.

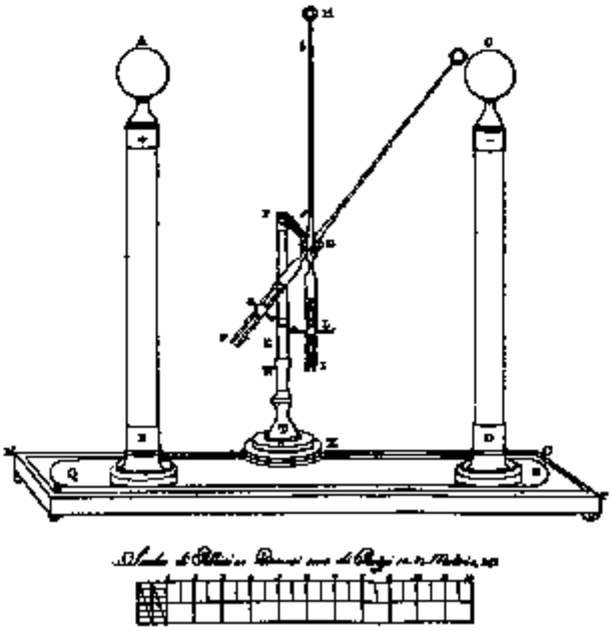

Fig. 7 Scheme of electric pendulum that constituted the first perpetual electromotive, drawn from "Descrizione ed uso dell'elettromotore perpetuo" of Giuseppe Zamboni.

The first experiments with pendulums called "perpetual" go back at Easter of 1812 when Zamboni by his intuition had balanced on a pivot a magnetic needle, that was in use on Nairne's declinometer, placed between the opposite poles of two his dry piles. The terminal of needle was attracted and repulsed from the poles of piles (the mechanism was based on attraction of pendulum caused by a pole of a pile, when the terminal arrived on the pole acquired charge of the same sign, it was rejected by that pole and attracted by the opposite pole of the other pile, and when it reached this one produced on pendulum a change of charges and so a repulsion, while the other pole became an attractor) so he obtained continuous oscillations on a horizontal plane. In July he had repeated the experiments, helped by the chemist Jacopo Bertocelli, and he was successful to regulate the distance of needle from terminals piles so that to obtain a kind of horizontal pendulum. At the end of the same year he thought to change the oscillatory motion in a vertical plane substituting the magnetic needle with a little brass bar.

The constructive care and the continual perfecting advanced the Zamboni piles to an high efficiency during the time and about their very long duration there was not any doubt, so much so that Zamboni and his collaborators applied them to true mechanical clocks with escapement, whose pendulum was moved by electricity, so he seem to have soled in that way the problem of their uninterrupted working. These clocks were realized thanks to the collaboration of mechanician Charles Streizig (machinist of the physics laboratory of Royal College) and Antonio Camerlengo, that with Antonio Pozzi (other assistants of Zamboni were Domenico Zamboni and Alessandro Bertolla) constructed some models during some years, at least till 1840. In this way it was eliminated the necessity of cyclic recharge with a simple and effective system. The participation of mechanicians expert in clocks mechanism was of great help for Zamboni to improve them, as count Scopoli quotes in Acts of Academy of Agriculture Commerce and Arts of Verona in 1824. "Posta la macchina in esercizio destò una piacevole sorpresa, ma il Zamboni s'avvide presto, che non corrispondeva alle sue speranze; onde si pose a meditare di concerto col macchinista nostro Antonio Camerlengo come giunger meglio all'intento, e il Camerlengo trovò il modo di far servire la potenza del pendolo oscillante fra le colonne elettromotrici a caricare l'orologio; ritrovamento che così all'Accademia che gli fè dono d'una medaglia del valore di 30 Zecchini.

L'orologio è in continuo moto, e potete esaminarlo nel gabinetto fisico, ove però il troverete ora assai più esatto per nuove aggiunte del solertissimo Zamboni. Sostituì egli al pendolo un volante superiore, che non fra due, ma fra quattro pile s'aggira in cerchio equilibrato, e perché nelle stagioni meno elettriche il peso non sia traboccante lo volle obbligato ad un attrito, che modera il suo abbassarsi con legge, direste, proporzionale".

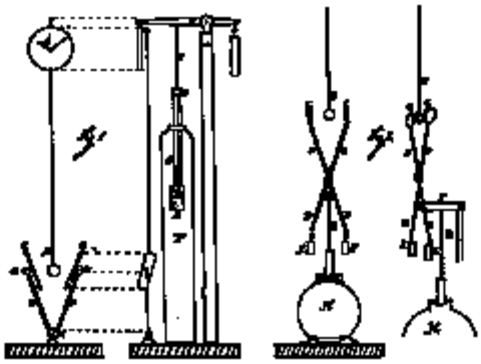

Fig. 8 Electromotrs kept in Liceo Classico Maffei in Verona, in a photo of 1929 (left), and at Liceo Classico Virgilio of Mantua (right).

Also the Science Academy of Paris in 1830 acknowledged the validity of his electrical machines. In a discourse read at the Academy during the meeting of 29 November Arago opened with these words: "In fatto di moto perpetuo nulla mai si farà di meglio del grazioso istrumento inventato dal signor Zamboni, il cui principio motore è l'elettricità delle pile conosciute col nome di pile a secco. Un piccolo corpo leggero sospeso ad un filo di seta tra i due poli di queste pile, è continuamente attratto e respinto dall'elettricità.

Questo moto non è già eterno, giacché nulla vi è di eterno nel mondo; ma dura molto tempo. Io conosco alcuni di questi istrumenti, ed io stessi ne costrussi parecchi che camminano da alcuni anni senza interruzione. Essi meritano dunque sino a un certo punto il nome di perpetui. E se questo meccanismo fosse applicabile alle macchine impiegate nelle arti, si potrebbe riguardare il problema come sciolto di una guisa soddisfacentissima. Molti tentativi furono fatti onde applicare questo principio motore all'arte degli orologi a pendolo, che si ricaricherebbero da loro stessi. Ma la forza è troppo debole, e sopra tutto cangiante; perciocché essa è soggetta all'influenza dei fenomeni atmosferici, e particolarmente alle variazioni di temperatura". At the end the report finished in a gratifying way. "Il moto perpetuo perciò del signor Zamboni non è che un istrumento straordinario ed interessante. I migliori esemplari vengono fabbricati a Verona dal bravo suo meccanico Domenico Zamboni".

The next year Zamboni sent a letter to the Science Academy of Paris that is the ideal continuation of Arago's assertions.

"Nella sessione del 29 novembre 1830, cotesta reale accademia si degnò di far parola del movimento prodotto dalla forza elettrica delle mie pile, che conta oggimai diciannove anni di vita perenne; e dichiarare altresì che la formazione di un orologio, coll'uso di tal movimento, darebbe sciolto il problema del moto perpetuo nel modo più soddisfacente. Le difficoltà di questa applicazione, messe innanzi all'Accademia, io già riconobbi in tante prove che andaron fallite; ma la perseveranza de' miei tentativi ebbe infine la mercede di un risultamento felice per via inaspettata. Imperciocché questa forza microscopica delle pile adoperata soltanto per muover aghi o volanti leggerissimi, vedesi ora immediatamente applicata a niente meno che un pendolo reale a secondi, mantener sempre vive le sue oscillazioni, e il moto del pendolo trasmesso ad un orologio semplicissimo dar la misura del tempo in ore, minuti primi e secondi. Perloché, sperando io che cotest'accademia voglia aggradir benignamente la notizia d'un apparecchio quasi da lei domandato, credo esser nel mio dovere il venire a lei descrivendo, ed offrirle così un tributo dell'alta mia riconoscenza pel favore onorevole ch'ella degnò destinare alle mie pile".

However Zamboni didn't limit himself to find the best combination of elements but strived to realize also the instruments to produce in the best way his piles and pendulums achieving at a production that today we call "a little series". In fact he was able to sell his piles to different colleagues for their physics laboratory, for the schools, to privates that put them in their house also as simple object of curiosity, realizing also simple equilibrium toys (pastimes) that were moved by the piles. Their construction was well tested, and they found estimators, above all in teaching field, also in Naples, as showed by a letter of Giuliano Giordano member of the Society of Jesus, who in 1841 asks Zamboni some notes and models of the piles to use in experiments for physics teaching in a school of Naples.

4. THEORETICAL MODELS

Zamboni had also worked about theory of electrochemical phenomena of piles and professor Ranieri of Pisa university had recognized that "il Sig. Zamboni avendo esaminate, ripetute, e variate le principali esperienze del fisico inglese, trovò col ragionamento e col fatto ch'elle sono del tutto insignificanti e illusorie". It was about the current debate to explain the electrical production phenomena with the hypotesis of electric fluid or galvanic fluid. His electrical machines were considered among the best at the moment, so that his perpetual pendulum was considered "come il più semplice, il più comodo, e più sicuro nell'effetto, che quello del suo celebre concittadino De Luc".

The contact theory that he developed was asserted with convincing experiments by Marianini and abroad by Becquerel, Davy, Psaff, against the famous Fusinieri's theory of attenuated matter. In this discussion Zamboni became part of the debate with energy and right born among physicians about origin of voltian electricity. The controversy was between those ones thought the effects depended by a chemical action, as the English Faraday and Swiss De La Rive, while at the opposite Becquerel, Davy, Psaff, Poggendorf, Marianini and Zamboni asserted the contact theory. Zamboni had a hard exchange of opinions with Ambrogio Fusinieri that had a great brain also in mathematics. Abbot Zantedeschi tried a mediation introducing a force called "polar activity of chemical action", not instant, but subsequent, that is born when the action of the fluid on solid surface become effective, that is the action of Fusinieri's "attenuated matter".

The Veronese Physician supported the Voltàs theory against the electrochemical theory, that he defended by a series of clever experiments with Stefano Marianini, Giuseppe Belli and Alessandro Maiocchi. In 1841 French Péclet published a work titled "About develop of static electricity in the contact of bodies (Annales de Chimie et de Physique, 1841) in which he remained in equilibrium between the Faraday's hypotheses of necessity of chemical action and the Voltàs hypotheses according to the tension was generated by the contact of metals. Here Zamboni answered immediately with the memo "Esame della memoria del sig. Peclet sullo sviluppo dell'elettricità statica nel contatto de' corpi" published in 1842 and that didn't at all agree with Péclet. He confirmed his ideas few months before his death, reading a further memo at Imperial Regio Istituto Veneto of Venice titled "Trattato di conciliazione degli Elettrochimici coi Voltiani".

5. RIVAL ELECTRICIANS

An interesting case of boasted primogeniture of electrostatic clock rised with Francis Ronalds (born on 21 February 1788 from a merchant in the City of London and native from Scotland; Aked 1973), that however had to use Zamboni piles, and that constructed unreliable systems because of the strong dependence by the weather conditions, at which he had tried to obviate with complex mechanisms of compensation without reaching the intent in a satisfactory way.

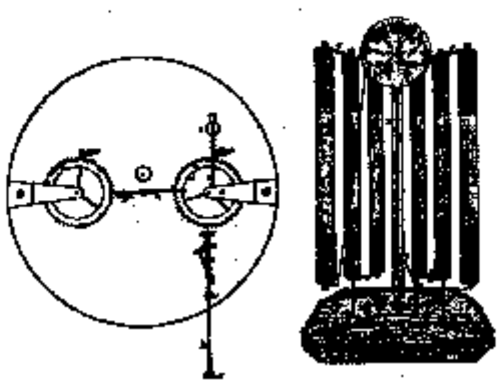

Fig. 9 Electrostatic clock set by Ronalds with De Luc' piles.

About paternity of electric clock there are two facts that are pro Zamboni. In 1815 he sent a letter to Royal Society with the schemes of his clock; besides in 1814 the squire Assalini, first surgeon of Prince Eugene [Eugen Beauharnais, Herzog von Leuchtenberg, Fürst von Eichstätt (1781-1824)] came to Verona to collect a pile for His Royal Highness and he was favourably impressed (Verona from 1805 to 1814 was part of the Italic Kingdom of Napoleon, and when this one collapsed, the viceroy of Napoleonic period, Eugene of Beauharnais step-son and adoptive son of Napoleon, moved to Munich to the father-in-law Maximilian I Joseph of Baviera with his personal doctor, the famous surgeon Paul Assalini). In Munich Assalini showed the running of Zamboni's electromotive at the Royal Academy of Sciences of Baviera, that gave commission to its mechanician, mister Ramis, to build a similar apparatus for the Academy collection. It was ready and then announced on 18 March 1815 (and experimented between 1815 and 1820 by J.C. von Yelin investment adviser and registrer of the physical-mathematical laboratory of Academy).

Already when he was young Ronalds showed remarkable mechanical ability and creativity, constructing many electrical and scientific apparatus; he was an excellent technical designer and he produced mostly the drawings used in his published works. He imagined to fit a pendulum to make to oscillate steadily a system to measure the flow of time regulating the charge quantity produced by the electric columns. He communicated the first results of his experiments on 9 March 1815 to mister Tilloch, owner of the Philosophical Magazine. So this date put Ronalds to be late because Zamboni had obtained the first experimental results in 1812, while the pendulum that he had presented officially was of 1814. Besides between 1814 and 1815 with his collaborator mechanician Charles Streizig he probably realized the first attempts to put in function a mechanical clock with his dry piles. However the Ronalds' announcement opens detailing his purposes and makes a brief story of electric column. "But I have constantly preferred the second method employed by M. De Luc for observing the phenomena of this curious instrument, which I have endeavoured to render more convenient by using a much larger ball on the pendulum; by making this pendulum of an inflexible wire instead of the fine silver thread; by causing it to partake of the motion of the common pendulum with that of the electric attraction, and by applying its vibrations to the motion of indexes. It would not be just to omit here my acknowledgement to Mr. Gorham, a very ingenious watch-maker of Kensigton, from whom I received great assistance, and who executed the mechanism of the wheels, levers, & c. in a very neat and accurate manner".

As we can see also Ronalds used a mechanician to set of the mechanisms for a real clock, as much as Zamboni was helped by Streizig. Moreover Ronalds continues: "It may be also easily conceived that the rapidity of the vibrations is influenced by the variations in the electromotive power of the column, which are occasioned by the circumstances stated by M. De Luc, Mr. Singer, and myself, viz, heat, moisture, and the electricity of the ambient air. ... and after several trials I adopted the following method, by which I succeeded better than I expected to have done in regulating the vibrations".

Therefore the Ronalds' machine suffered considerably of variations of the weather conditions and it was far away from an acceptable stability during the time and from simplicity of setting. In fact "The columns represented in the plate have kept the pendulum thus circumstanced in activity about three weeks. When the temperature of the room is above 53 degrees, it gains about two seconds in five minutes for every advance of one degree; but when it is below this degree it diminishes its velocity gradually, until it no longer vibrates so fast as seconds". We can consider that a clock which changes of two seconds in only five minutes caused by changing of temperature of one Fahrenheit degree is not to take seriously into consideration. This situation represents a change of 10 minutes every day for one degree.

Ronalds' letter to Tilloch had arrived just in time to precede the publication of a letter of professor Ramis on 18 March 1815 about his "Electric clock with pendulum" copied from that one of Zamboni, and however the electric system of Ramis was more similar to a clock than that one of Ronalds. On 15 September of the same year Ronalds wrote to Tilloch another note entitled "On correcting the rate of an electric clock by a compensation for changes of temperatures", from which we see the necessary complication that Ronalds had to introduce to get an acceptable regularity of working. "Having at different intervals, made fresh attempts to render Mr De Luc's column applicable to the measure of time, and being now obliged to discontinue them by a long absence from London, permit me to describe that which has been most successful, in the hope that some person better qualified for the subject may deem worthy of attention. I have, by the following method, procured a better compensation for the effect of an increase of temperature, which, by increasing the power of the column, accelerates the velocity of the vibrations.

A beam is suspended like a dipping needle s nearly as possible in its centre of gravity,carrying at one end the clock, and at the other a weight almost counterpoizing it. A spirit thermometer of nearly the same kind as those used in France (to mark the degree of heat by an index) is placed under the beam; the part containing the spirit is 35 inches long, and one inch bore, and the part which contains in its lower end the mercury is half an inch bore".

In spite of all this work Ronalds had to admit also that "the principal defects are now those arising from a difference between the rates of heating and cooling of the spirit thermometer and the columns, and from some unknown circumstances which has been attributed to the electric state of the ambient air. The larger the series employed, and the heavier the pendulum, the more correctly it seems to vibrate".

Amongst other interesting intelligence from your learned correspondent M. Van Mons, it appears that Sign. Zamboni has been enable to produce strong sparks and shocks by the column, , the construction of which he seems to have thus very greatly improved. With the help of a condenser I have advantageously substituted it for the electrophorus in Voltàs inflammable air-lamp, which is apt to get out of order; but Sign. Zamboni's columns could be used without this assistance". Here then that in September 1815 Ronalds had to use Zamboni columns, but he arrived late.

Another English scientist, George Singer, in fact had to acknowledge that "the most elegant and at the same time the most simple movement yet produced by the electric column appears to be that employed by Signor Zamboni, who has made some interesting discoveries on the general structure of the instrument.He employs a vertical needle supported by a delicate pivot or knife-edge a little above the centre of gravity, the position of which may be readily altered by means of a sliding weight attached to the lower extremity of the needle, which may by that means be so adjusted as to possess the properties of an accurate scale-beam, and will maintain its oscillations over a considerable space by a very slight impulse".

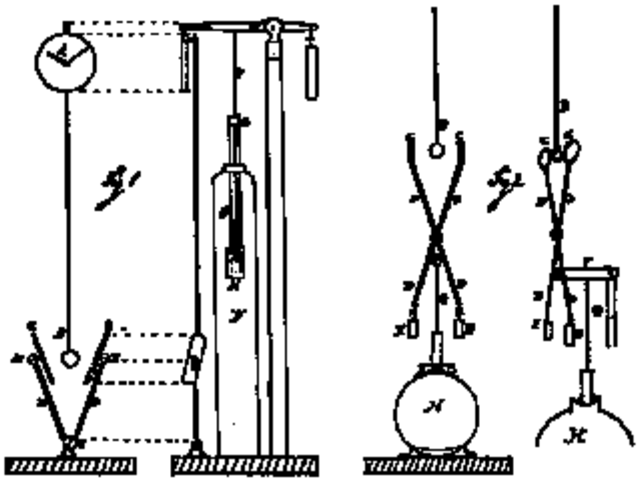

Fig. 10 Compensation system to control the frequency variations of oscillations adopted by Ronalds for his pendulum.

Then there is a last point pro Zamboni: we know that at the beginning of 1815 he had sent a report and a pendulum to Joseph Banks, President of Royal Society, who wrote in a letter to Ronalds: "The instrument you allude to in your letter I conclude is a modification of the Mr De Luc's contrivance by a Member of the name of Zamboni it was at my house ... and is now in the apartment of the Royal Society in Somerset Place".

An ulterior Ronalds article on 6 June 1815 on Philosophical Magazine entitled "On the Electric Column of Mr. DE LUC" confirm the primacy of Zamboni, also denying the evidence: "Since you did me a favour of inserting in your valuable Magazine a description of my contrivance for applying clockwork to Mr. De Luc's electric column, for the purpose of observing with greater facility and convenience its meteorological phenomena, and for attempting to procure by its means a measurement of time ... I can pretend to Mr. De Luc remarks that the instrument is not to be called electric-galvanic but electric column ... The reason of my concurrence with him in the use of the terms electric column and electric agency s because I think his ingenious experiments and forcible deductions, and their subsequent confirmation by the experiments of Sig Zamboni and others, go far to prove the truth of the proposition which Mr. De Luc here advances".

6. PILES, PENDULUMS AND CLOCKS STILL PRESERVED

By researches carried out we found a certain number of piles, pendulums and clocks that are still preserved almost all in a good condition and that are distributed in some Italian city. In 1972 Mr. Paul Forlati of Verona, an expert of mechanics and history of the clocks, restored a clock realized by mechanician John Bianchi in collaboration with Zamboni. It is a clock equipped of escapement with rungs moved by a pendulum moving between two copper polar plates, in origin supplied by Zamboni's piles, today restored with a transformer. It is placed in a wood and glass chest in pure Empire style with Napoleonic little eagles. It is located in a family of Milan that had it as heritage coming from their Veronese ancestors to whom it was given as wedding present by Zamboni himself. The piles were reconstructed by the proprietary with thousands discs of tinfoil, paper without glue, coal and adhesives regenerated from those ones studied in origin. However the attempt didn't give satisfactory results.

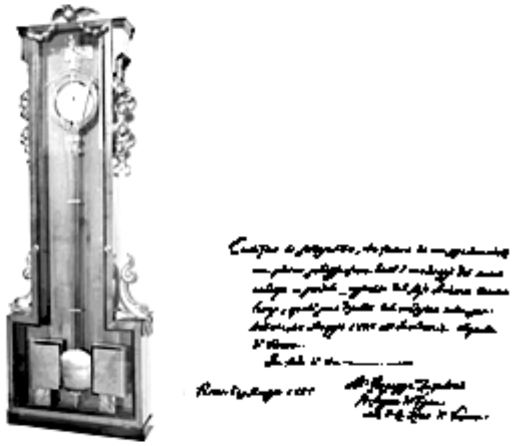

Fig. 11 Pendulum clock realized by Antonio Camerlengo working with Zamboni's piles and certified for the Agriculture, Commerce and Arts Academy in 1827, property of Mr. Paul Forlati (left). Autograph certification by Zamboni regarding the good working of the pendulum clock constructed by Camerlengo (right).

Two very fine original models of pendulum clocks (one of them realized by mechanician John Bianchi), very valuable aesthetically, are visible in the headmastership of Liceo Classico "Scipione Maffei" of Verona, and they were restored by Mr. Forlati too, although lacking of the original piles, substituted by transformers. In the physical laboratory of the same college there is also a pendulum complete of original piles. All these apparatus had surely worked at least till 1930 with the help of only their piles.

Fig. 12 Pendulum mechanical clocks moved by the Zamboni's piles preserved at Liceo Classico "Scipione Maffei" in Verona (The relative proportions of the clocks ar not maintained)

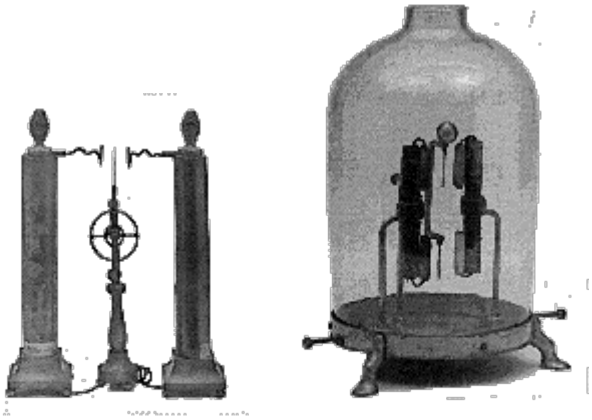

Fig. 13 Zamboni's Pendulum electromotive (left) and Perpetual Motion (right), treated from volume "Duecento anni di elettricità", catalogue of the Museum of Physics History in Padua, p. V5 e V6.

A precious pendulum-clock belongs to Mr. Forlati: the mechanical part was realized by Antonio Camerlengo, mechanician of Agriculture Commerce and Arts Academy (in which today it is preserved a little original dry pile), endowed of Zamboni's piles and certified by Camerlengo and by Zamboni with two documents of 1827.

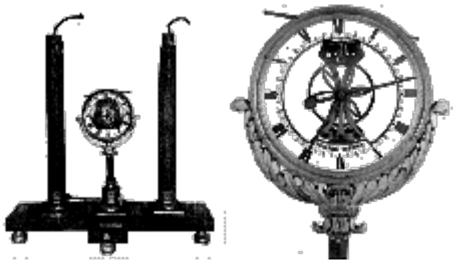

Fig. 14 Mechanical clock with Zamboni's piles constructed by Charles Streizig and kept at Civic Museum of Modena. At right a foreground of the clock.

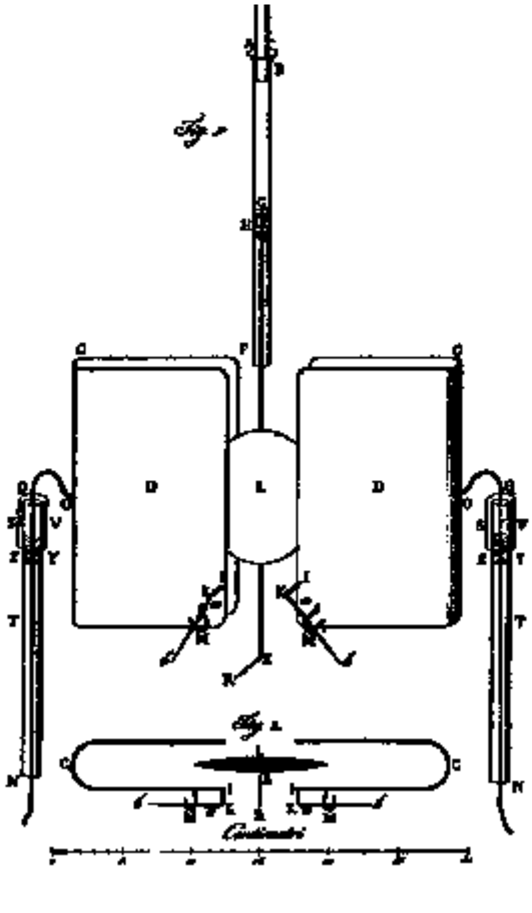

Fig. 15 Control system of pendulum with the use of plates of great dimension, from "Lettera all'Accademia Reale delle Scienze di Parigi", Poligrafo, March 1831

A pendulum with relative little piles, high about 30 cm, is kept in a very good state in the collection of ancient physical instruments of Liceo Classico "Virgilio" of Mantua, with a little autograph paper of Zamboni containing a list of ingredients probably used to build those piles.

Two models are preserved at the Museum of Physics History of Physics Department of Padua University: they are a pendulum (or perpetual electromotive) with two piles high 60 cm used by professor Salvatore Dal Negro, and a perpetual motion with four piles much smaller and coupled in two pairs, with brass plates between which oscillate two straws of oats, both dated 1830. Surely the first worked still in 1930 as testified the director of the Physics Institute. Further these ones there are two Zamboni's piles with little discs stacked without protection tube, long 30 and 32 cm, realized near 1900 and used by professor Bellati and professor Vicentini.

A model of electromotive was signaled in 1930 in the Physics Institute of Siena University, instrument that Zamboni had dedicated to Ferdinand II king of Etruria and constructed by Charles Streizig in 1816.

In Modena, in addition to the above quoted pendulum that may be found at Physics Institute, is preserved in Civic Museum a variant no more working of a mechanical clock high about 40 cm with two piles high about 60 cm, realized by Charles Streizig and found by professor Rizzardi that supposed dated back 1817 when Antonio Pozzi invented large plates to pilot the pendulum with electricity.

7. OTHER REALIZATIONS OF GIUSEPPE ZAMBONI

The interests about electrical phenomena beared also to perform an universal apparatus to measure the electrodynamic attractions and repulsions between electric and magnetic currents that is the force between currents when changing of a magnetic field, or a magneto-electric micrometer. Moreover he set a mechanism easy to realize and simple to handle to test experimentally the laws about centrifuge force in function of the acting masses, the masses speed and the rays of traced curvature. It was an improvement in comparison with the complex apparatus used by Nollet.

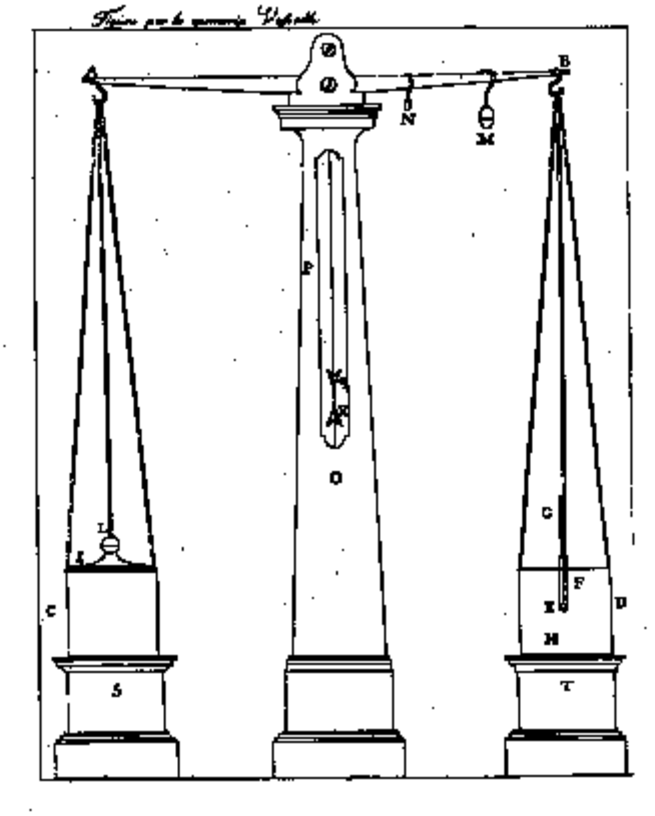

Fig. 16 Hydrostatic apparatus devised by Giuseppe Zamboni, from "Dell'apparecchio idrostatico più semplice ed universale. Memoria", in Memorie della Società Italiana delle Scienze (Memorie di Fisica), vol. XIX, part 2deg., 354, 1825

One of the best realizations was a universal dynamical very sensitive electroscope, that improved that one of Nobili and able to measure induction currents, based on a coil crossed by a changing current, hinged but free to move on an axis (in a different way of the use of that time). A powerful iron magnet having the shape of a horse-shoe contained, between polar expansions, the coils with the attached indicator. De Luc made similar trials. Behrens had applied the dry pile at an electrometer with an auxiliary field, in which the poles of pile were connected to two little metallic parallel discs and between them hung a metallic leaf. At the end Zamboni had developed an hydrostatic apparatus (or balance) to do some experiments about characteristics of fluids with the greatest simplicity "acconcio a tutte le sperienze fondamentali dell'Idrostatica".

8. THE DEVELOPMENTS OF ZAMBONI'S PILES

After the death of Zamboni the interest for his piles decreased very much, probably the times were not mature, however after less than a century we find them again protagonists in the catalogues of materials for laboratory, then during the second world war. The Zamboni's system of construction is assimilated out of Italy, in fact we find his name on the catalogues of electric and electromechanical instruments, as those ones of the first year of 1900. The Zamboni Column of Elster & Geitel with 1000 discs in models with different tension, on the catalogue Physikalische Apparate di Ferdinand Ernecke, Wersktätten für Präcisions-Mechanik of Berlin, Zamboni's dry piles with protector sheating at 300-350 volts, with poles seated in ebonite plates with surface artificially extended. Or the Zamboni's pile of Elster & Geitel modified by Noack, composed by 1000 or 2000 little sheet of golden and silver paper with brass discs for the couplings to allow the withdrawal also of a partial tension, or the Zamboni's pile in gold and silver paper with glass fitting and terminals at the poles and variable selection among 1000 and 6000 discs, with diameters from 28 to 50 mm, publicized in the catalogue Appareil de Physique (1906) of Max Kohl A.G.

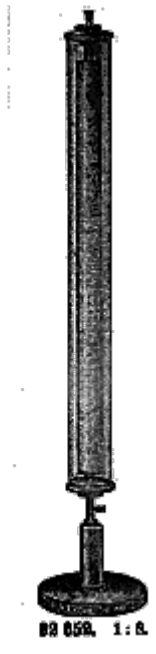

Fig. 17 Pile standard Zamboni with 5000 pairs with 40 mm of diameter, from Max Kohl A.G., Appareils de Physique, Chemnitz, Allemagne, catalogue n. 100, vol. III

The story goes on during the second world war. While Italian people were satisfied with "twenty million of bayonets" and the Fascist rhetoric, English people, with solid scientific traditions, had studied again and rebuild some Zamboni's piles able to supply also 5000 volts. The exceptional characteristics of these piles were recognized by English scientists, that have a long tradition in science history. They recovered the ideas of abbot, remembering also that a model of dry pile constructed at Clarendon Laboratory of Oxford University in 1840 had worked until the half of 1900.

They studied them at the Admiralty Research Laboratory, and were rebuild on great scale at the Home Park Mills at Kings Langley near Tottenham in a great number of models, renewing in part the technology that in 1945 was more advanced than the previous century. The piles were used as a light and handy source of electric energy to supply the infrared viewer (tube) used by British Services: they served for nightly viewer during war mission. In fact during the summer of 1940 a converter tube to transform an image from infrared to visible was set by E.M.I. Ldt, and followed later the first photomoltiplier tubes realized by Holst and collaborators. The piles supplied tubes with a tension between 2000 and 4000 volts, with a current of 10^{-9} ampere, limited by an internal resistance of some thousands megaohm.

The first English attempts were obtained splattering a thin mixture of starch paste (provided by Lyons Ink, Ltd. and Sichel Adhesive Ltd.), manganese dioxide and traces of zinc chloride on paper (provided by East Lancashire Paper Company, known as Gumming d/G, 26, 516's, 20,5 inches, made with the standard John Dickinson and with a thickness of 0,0838 mm). After the drying the paper was covered with tinfoil using a little of paste as binder. The first results gave a pile with 0,6 volt for every disc. An improvement was obtained with a new binder mixture composed by manganese dioxide (150 gr) (provided by by British Drug Houses, Ltd., Boots Ltd. and Venesta Ltd.), baked jelly (25 gr) (made by British Glues and Chemicals, Ltd., and provided Boots Ltd., called 150 T.G.), solution at 10% of zinc chloride (13 cm^3), water (700 cm^3). In this situation it was fundamental the type or adhesive used that hadn't have for an electric resistance too high when it was dry. The Stationary Office Glucine Paste, code No. 69-16 was believed suitable. Then a little quantity of turpentine was added to the solution to prevent the frothiness, with a manufacture that obtained every complete sheet at the thickness of 10^{-1} mm. The discs obtained from the sheet were packed in tubes of cellulose nitrite long at least 16,5 cm and also more than 2 cm in function of required voltage, with external brass caps sealed with painting with a basis of cellulose. To increase the insulation in more difficult ambients they were also soaked in melting wax. Later tubes made with methyl methacrylate were used. The optimal work conditions were evaluated in this way: 55% of atmospheric humidity, temperature 20deg..

Another power supply similar to the Zamboni's pile was realized by the American Clarence Haberer living in Louisville, Kentucky, with discs of 55 mm of diameter, using paraffin paper on whose surfaces was smeared a little of graphite, while tube was in Pyrex.

After the war the piles were used also in astronomical field to supply the infrared photodetector assembled on a telescope, but the application of the longest duration of the piles model Zamboni remains the Bohnenberger electroscope with auxiliary field and high sensitivity.

Later also the Machine-shop Galileo in Florence began the realization of Zamboni's piles, in compact version, used until 1950 as educational aids for the laboratory exercises. They were composed by 1000 or 2000 pairs of discs of silver and golden paper, supported by an ebonite rode and pressed between two plates with hooked terminal.

PUBLICATIONS OF GIUSEPPE ZAMBONI

On this occasion I collected in all works published by Giuseppe Zamboni, or posthumous printed, whose citations were spread in various articles, biographies, books, notes and that I recovered mainly through the archive of Civic Library of Verona, that preserved a great part of them. Instead some articles are in the Episcopal Seminary Library of Verona, one of them is in Central Library of Padua University and one at National Library of Rome.

Saggio teorico sperimentale di fisica sulla gravità de corpi che sotto la direzione del signor Giuseppe Zamboni Sarà dato dai Signori Giuseppe Vincenzi, Gaetano Brugnoli, Vincenzo Guerrieri Alunni di

merito pari nel suddetto Liceo, Dionisio Ramanzini, 1810, Verona

Sull'identità del fluido elettrico col fluido galvanico, letto all'Istituto di Francia, 1811?

Della pila elettrica a secco. Dissertazione, Dionigio Ramanzini, Verona, 1812

Lettera all'Accademia di Monaco sui miglioramenti fatti alla pile stesse, Verona, 1812

Dissertazione sulla pila elettrica a secco, in Giornale di Fisica, Chimica, Storia Nat., Medicina ed Arti, ed Brugnatelli, vol. 5, pp. 424, 1812

Lettera ad Alessandro Volta, Verona, 24 agosto 1812, in Le opere di Volta, Edizione Nazionale, Hoepli, Milano, 1927

Lettera ad Alessandro Volta, Verona, 12 settembre 1812, in Le opere di Volta, Edizione Nazionale, Hoepli, Milano, 1927

Descrizione della colonna elettrica del Sig. De Luc, in Giornale di Fisica, Chimica, Storia Nat., Medicina ed Arti, ed Brugnatelli, vol. 6, pp. 31-43, 1813

Descrizione ed uso dell'elettromotore perpetuo, Tipografia Mainardi, Verona, 1814

Giornale dell'Adige, 19 gennaio, 1814

Dissertazione sulla pila elettrica a secco, in Giornale di Fisica, Chimica, Storia Nat., Medicina ed Arti, ed Brugnatelli, vol. n. 7, pp. 220, 1814

Dissertazione sulla pila elettrica a secco, in Giornale di Fisica, Chimica, Storia Nat., Medicina ed Arti, ed Brugnatelli, vol. n. 7, pp. 444-445, 1814

Annalen der Physik (Gilbert Annalen), vol. 49, 41, 1815

Annalen der Physik (Gilbert Annalen), vol. 51, 182, 1815

An Instrument of his own Construction, Presented to the Royal Society ... an attempt ... at Perpetual Motion, Philosophical Magazine, xlv, 67, London, 1815

Sopra i miglioramenti da lui fatti alla sua pila elettrica, Lettera all'Accademia Reale delle Scienze di Monaco, Tipografia Ramanzini, Verona, 1816

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