Antonio Pacinotti's life and work

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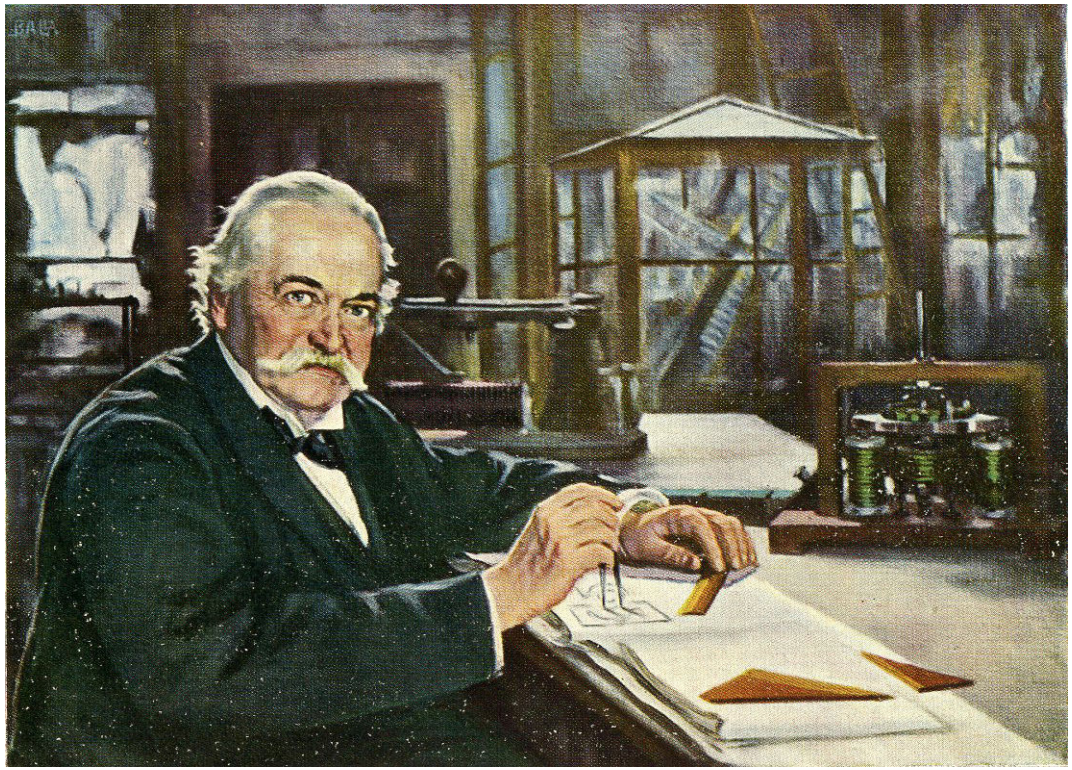


Painting by Giacomo Balla (1871-1958) depicting Pacinotti in 1911, One recognizes a copy of the macchinetta and the clew machine.

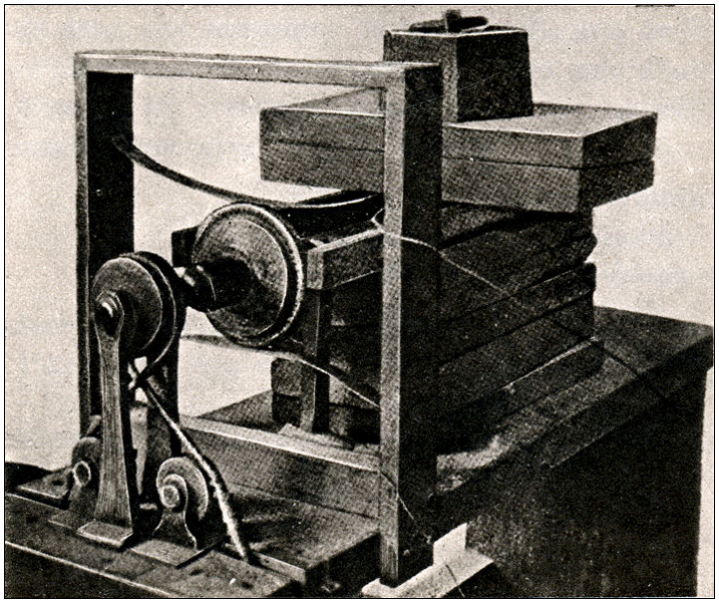
Antonio was born in Pisa on June 17, 1841 by Luigi Pacinotti from Pistoia and by Countess Caterina Catanti from Calci.

He studied in Pisa: Istituto Guadagnoli, Collegio di Santa Caterina and university entrance exams in 1856.

During the academic year 1857/58 he studied carefully and independently the *Traité d'électricité théorique et appliquée* by Auguste de La Rive (I-III, Paris, 1851-58).

On January 10, 1859, when he was not yet 18, in the first of his (lifelong) notebooks, called «Dreams», he described an experimental apparatus consisting in the first DC dynamo-motor machine. Later on, in the same notebook, he remarked that it would work well both as a dynamo and as an engine.

The first prototype of a DC dynamo-motor machine consists in a closed spiral of conducting wire wrapped around a ring of soft iron that, rotating within an external magnetic field directed along its diameter, could generate a continuous current extractable by electrodes resting on the closed spiral and placed along an axis orthogonal to the external magnetic field. If the apparatus was turned by hand, a direct current was generated, while if continuous voltage was applied to the electrodes the device would rotate.



Reconstruction of the first experiment based on the Closed ring, realized by Pacinotti in 1911

Pacinotti's Closed Ring

In an autograph composed between 1860 and '62 one can find a theoretical attempt on electromagnetic machines, that until then had been studied only by M. Jacobi. Pacinotti mentioned it in the Report sent to the jurors of the 1884 Turin exhibition

Antonio dressed as a voluntary sergeant
In the body of engineers

Eager to take part in the second war of independence (his father Luigi had fought in 1848 in Curtatone, as captain of the 2nd company of the Pisan university battalion), Pacinotti abandoned his research and university and on May 10, 1859 he left for Lombardy as sergeant in the body of military engineers. However, he arrived at the end of hostilities and was dismissed on July 21.

Returning to his studies, together with Giuseppe Poggiali, the mechanic of the technological physics cabinet, he built and experimented in April 1860 what he called macchinetta, the first electric DC dynamo-motor machine.

The macchinetta solved the two main problems of the machines built until then: the rectified AC and the low efficiency.

Antonio, hoping to find funding for a larger model, did not publish the discovery

Since 1832 dynamos existed but they all produced an alternating current, eventually rectified with devices called switches and with a low efficiency. The necessity of that period was instead to obtain a direct current for industrial uses at low cost, impossible, if not in rare cases, with the expensive apparatus derived from Alessandro Volta's pile. There were also electric cars functioning as non-reversible engines but in that period they were not of industrial interest.

On June 28, 1861 he received a doctorate in applied mathematics.
In the academic year 1861-62 he was assistant to his father and on May 9, 1862 he was appointed assistant of the astronomy professor Giovan Battista Donati in the Institute of Higher Studies of Florence.
In 1863 he accepted the teaching of physics at the Collegio Cicognini di Prato to renounce it after a short time.
In this period he worked on astronomy and optical instruments, participating, among other things, as a founding partner with Donati, at the start of a workshop for the production of precision optical instruments that, in 1870, became the Officina Galileo.

On December 4, 1864 he moved to Bologna as the winner of the Physics and Chemistry chair of the Royal Technical Institute. Not having received any attention, in five years after the discovery, neither from the industrial environment nor from the university, he finally decided to publish an article entitled Descrizione di una macchinetta elettromagnetica in the journal *Il Nuovo Cimento* (XIX, pp.378-384). published on May 3, 1864

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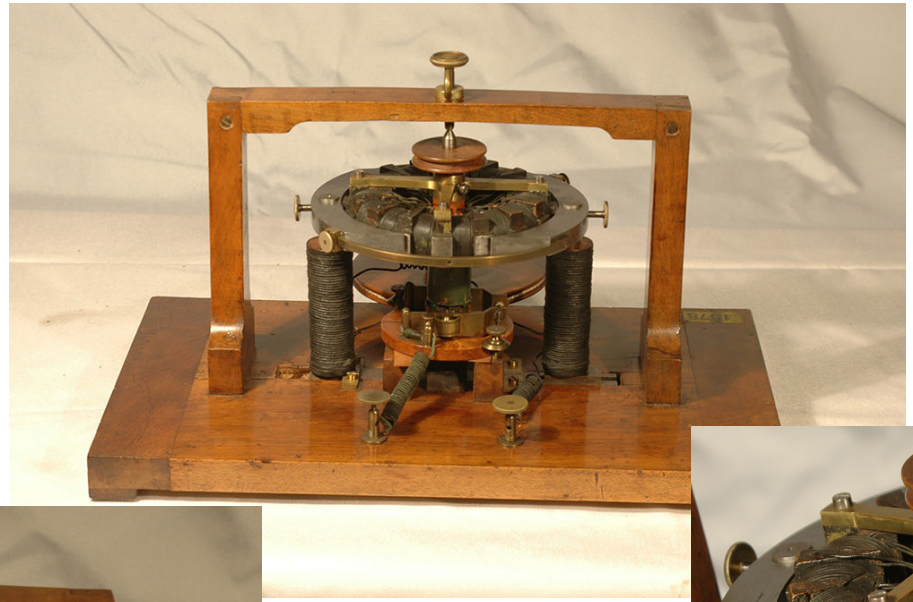
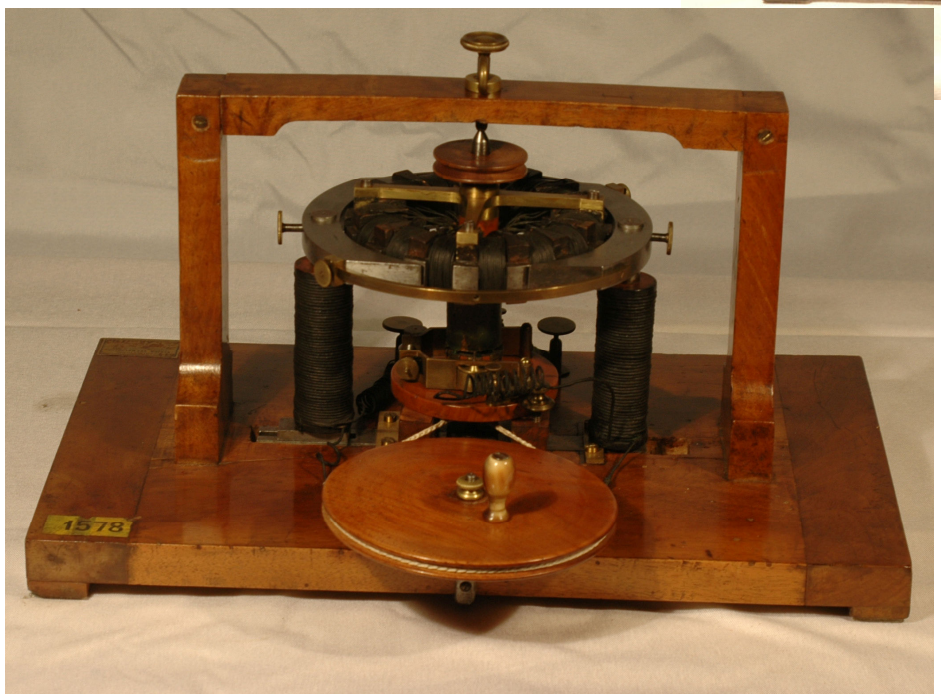
DESCRIZIONE DI UNA MACCHINETTA ELETTRO-MAGNETICA
DEL DOTT. ANTONIO PACINOTTI.

Nel 1860 ebbi occasione di far costruire per conto del Gabinetto di Fisica Tecnologica dell' Università di Pisa un modelletto di macchina elettro-magnetica da me immaginata, e che ora mi risolvo a descrivere specialmente per far conoscere una elettro-calamita di genere particolare usata nella costruzione di quella, la quale oltre la novità che presenta, mi sembra adattata a dar maggior regolarità e costanza di azione in tali macchine elettro magnetiche, come anche la sua forma mi sembra conveniente per raccogliere la somma delle correnti indotte in una macchina magneto-elettrica.

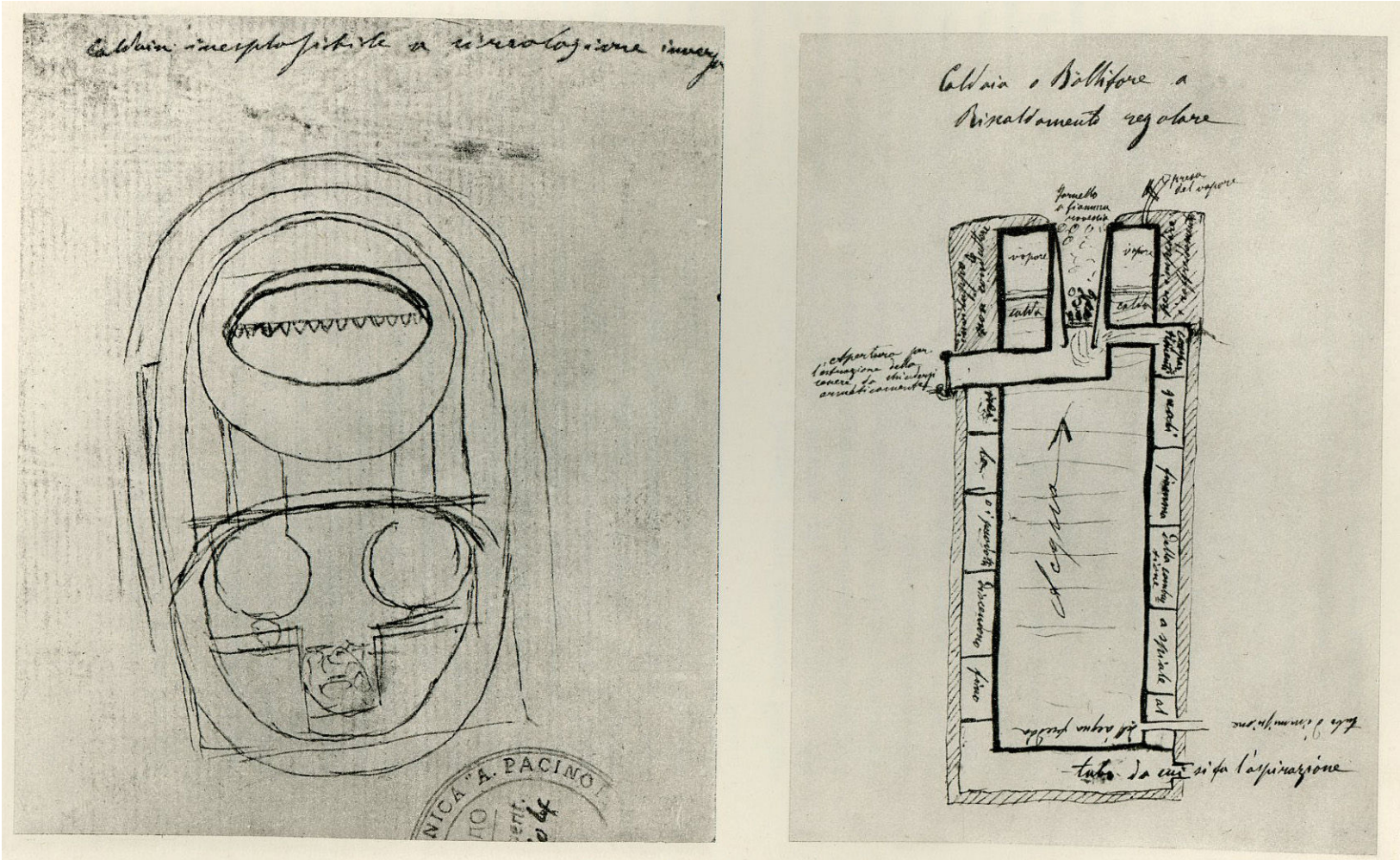




From July 1 to September 30, 1865 he was seconded to the Ministry of the Navy for a trip to Europe in order to visit the meteorological services active in the main cities. The objective of the trip was to acquire the knowledge and the necessary equipment to set up a meteorological service in Italy; Pacinotti had received this assignment from Carlo Matteucci, responsible for the program.

Hoping that the trip could be an opportunity to find financiers for the construction of a larger version of his 'macchinetta', he brought with him fifty copies of the article that described it, to distribute them along the journey. The departure took place on July 14 and Pacinotti was accompanied by his brother Giacinto.
They made stops in Paris, London, Brussels, then again in Paris and finally in Geneva, and returned to Italy in early September.
As shown by letters to his father, during the first stop in Paris - and not during the second, as Pacinotti himself stated in his writings and interviews - he visited the Froment workshops and met Zenobe Gramme, author of the 'usurpation' (as Werner Siemens called it in a letter to Pacinotti on February 12,1875) of the 'macchinetta'.
Returning to Bologna, he continued his teaching in physics and chemistry at the Royal Technical Institute, becoming in 1868 professor regent of general and applied physics and in 1871 titular professor.

Although his greatest commitment was the design and construction of electromagnetic machines, his interests ranged from astronomy to optics, from the interaction between solar heat and electric currents to technical applications in the agricultural field. On all these subjects, as early as 1873, 28 publications by him were available. In the field of agricultural technology, in particular, that he had approached for personal and family interests, he conceived and created the 'kalefactor tube' for the heating of the barrels, the 'piping vats' for the fermentation of grapes and some appliances for winemaking systems. He presented all these devices in various exhibitions, from 1868 to 1886, often receiving official acknowledgments.



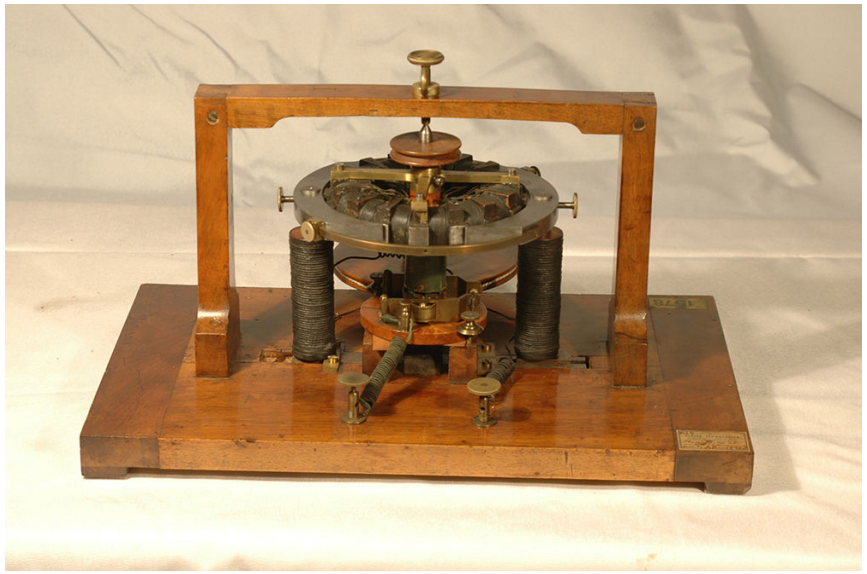
Schizzi di caldaie

While he was in Bologna the controversy began on the priority of the invention of the DC dynamo-motor.

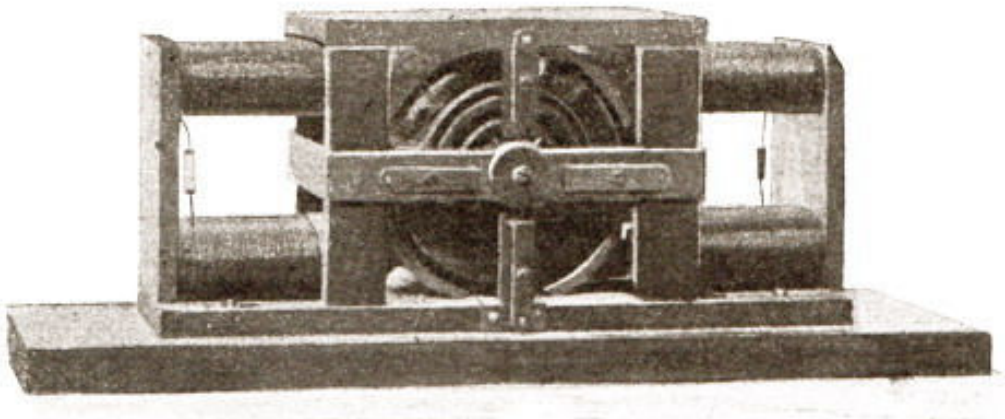
In 1871 he read in the *Comptes rendus* of the Paris Academy of Sciences that Jules-Célestin Jamin had presented a memoir of Zenobe Gramme about a dynamo-electric DC machine he had designed and built (this machine was the result of a series of patents requested by Gramme since 1867 and the machines produced by him were marketed since 1872).

Pacinotti recognized in that article his 'macchinetta'. He remembered his meeting in Paris with Gramme in the Froment workshops in the summer of 1865 and realized that he had made a mistake leaving his memory and giving in-depth oral explanations. He then wrote to the Academy of Sciences and to Jamin, recalling the history of the 'macchinetta' and his letter was published favorably and almost entirely on the *Comptes rendus*.

In the following years (until 1905) several articles followed both in favour and and against the point of view of Pacinotti and he wrote several replies. However, only at the 1881 International and World Electricity Exhibition in Paris he obtained the final recognition as the creator of the first DC dynamo-motor and this recognition was sealed by the President of the French Republic who granted him the membership of the Legion of Honor.

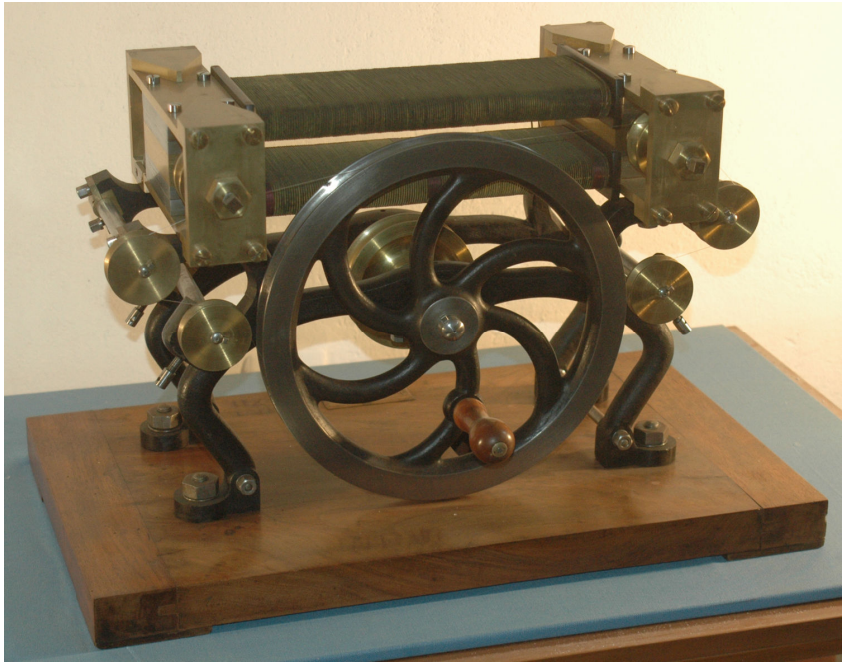


La macchinetta di Pacinotti (1860)



La prima macchina dinamoelettrica di Gramme presentata nel 1871

The first machine built after the «macchinetta» was a magneto-electric machine based on the Ladd system, which he described in an article on Il Nuovo Cimento of 1870. The machine was ordered by his father Luigi in 1867 but he directed the construction in Bologna by Francesco Pizzorno, the technician of the institute.



This machine was presented at the 1869 Bologna exhibition, probably together with the 1860 Macchinetta.
The article says:

In the 1869 Bologna exhibition the dynamo-electric machine was in communication with a small electro-magnetic motor placed at the other end of the bench, and it was enough to turn the machine a little to see the engine running. Thus a very curious transmission of movement was highlighted, [...].

ON THE OTHER SIDE OF THE BENCH THE MACCHINETTA WAS PROBABLY INSTALLED. HENCE THIS LITTLE EXPERIENCE PROVIDED BOTH AN EXAMPLE OF REMOTE TRANSMISSION OF MECHANICAL ENERGY AND OF THE REVERSIBILITY OF THE MACCHINETTA, I.E. ITS OPERATION AS AN ELECTRIC MOTOR.

On March 30, 1873 Antonio won the competition for the chair of professor of experimental physics and director of the relative cabinet at the University of Cagliari and in the same year he realized two electromagnetic machines: the angular Diverter and the dynamo-electric clew machine

The angular Diverter, presented in *Il Nuovo Cimento* in 1873

THE ANGULAR DIVERTER CONSISTED OF THE TRANSVERSE ELECTROMAGNET AND THE COLLECTOR OF THE MACCHINETTA MOUNTED SEPARATELY ON TWO WOODEN PLANES, ALLOWING TO DETECT ANGULAR DISPLACEMENTS IN PLACES INACCESSIBLE TO ONE'S SIGHT.

THUS WHEN AN EXTERNAL ROTATING APPARATUS WAS CONNECTED TO THE CYLINDER AXIS, THE CYLINDER ROTATED ACCORDINGLY AND THE HIGHER POTENTIAL WHEEL SENT AN ELECTRICAL SIGNAL TO THE OTHER ELEMENT ON WHICH THE MAGNETIC NEEDLE COULD ROTATE, INDICATING THE DEVIATION OF THE APPARATUS.

The clew machine

The clew machine, presented in a 1874 article of *Il Nuovo Cimento,* introduced a new transverse magnet consisting of a full iron cylinder with a wire wound around it like a ball of wool. Antonio started to build this machine at the Villa di Caloria (Pistoia) and completed it in Cagliari.

According to Pacinotti the machine, despite its small size, could have produced a fair amount of current by means of considerable mechanical work, which however he could not reach it notwithstanding help by three men. This machine participated in the Paris exhibitions of 1881 and 1900 and those of Turin in 1884 and 1898.

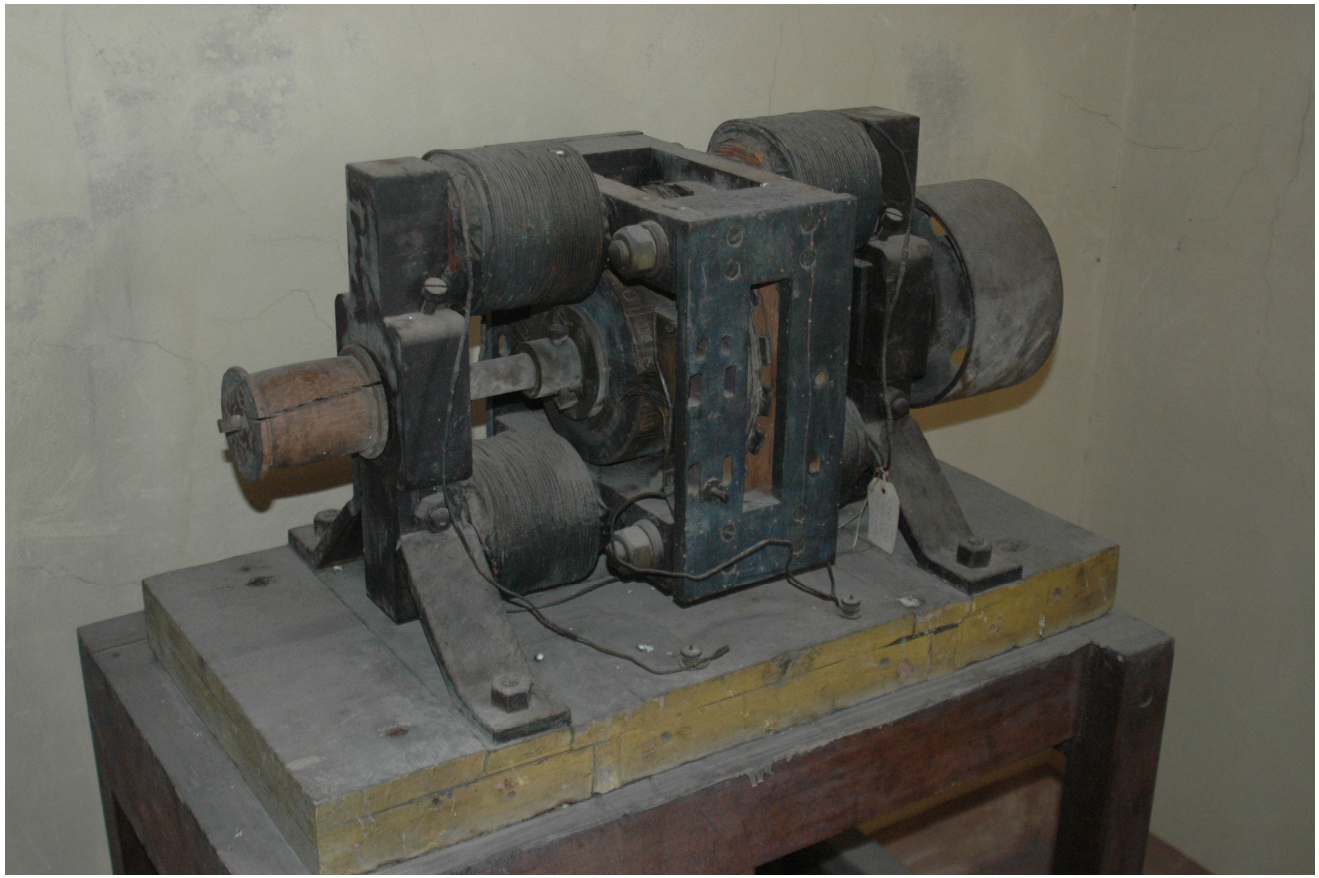
Initially the Cagliari period appeared to Pacinotti as an exile, especially since the laboratory was not adequately equipped for his research. In the academic year 1874-75 he returned to Pisa to help his sick father but then, being back in Cagliari in the following year, with time he adapted so well to the life of the island that, when on December 15, 1881 he was appointed professor of technological physics in Pisa, he even tried to have the appointment cancelled, even if it was an excellent career advancement. The nomination had been strongly supported (without his knowledge) by his father who wanted to leave the chair because of his own age. Despite his efforts, Antonio only got to stay in Cagliari to finish the lessons of the current year.

THE CHANGE WAS PROBABLY DUE TO TWO FACTORS: FIRST, THE PHYSICS LABORATORY HAD BEEN EQUIPPED, THANKS TO VARIOUS EXTRAORDINARY LOANS AND TO A FAVORABLE ATTITUDE BY THE CAGLIARI UNIVERSITY; SECOND, HE HAD MET THE NINETEEN-YEAR-OLD MARIA GRAZIA SEQUI-SALAZAR, WHOM HE MARRIED IN CAGLIARI ON 29 APRIL 1882. SHE DIED IN CHILDBIRTH IN PISA ON FEBRUARY 25 1883.

The most important research of this period was the study of the electricity generated by the rubbing of different materials. This earned him four full-bodied publications in the *Nuovo Cimento* between 1874 and 1875.
For these experiments he also designed and built devices called "tripods" which were exhibited in Paris in 1881 and in Turin in 1884 and 1898.

Since Spring 1875 Antonio began studying the electromagnetic flywheels and built the first one in Cagliari in Spring 1878 with the help of the workshop Doglio and of the mechanic G. Dessì [...]

THE «ELECTROMAGNETIC FLYWHEEL» WAS, AFTER THE «CLEW», ANOTHER WAY OF WRAPPING THE WIRES TO OBTAIN THE ARMATURE, BUT NOW THERE WERE NO FERROUS PARTS INSIDE THE «FLYWHEEL», ON ITS AXIS HE LOCATED THE USUAL PACINOTTIAN SWITCH WHICH, TOGETHER WITH FIXED MAGNETS, CONSTITUTED THE MAGNETO-ELECTRIC MACHINE WITH A TRANSVERSE ELECTRO-MAGNETIC FLYWHEEL.

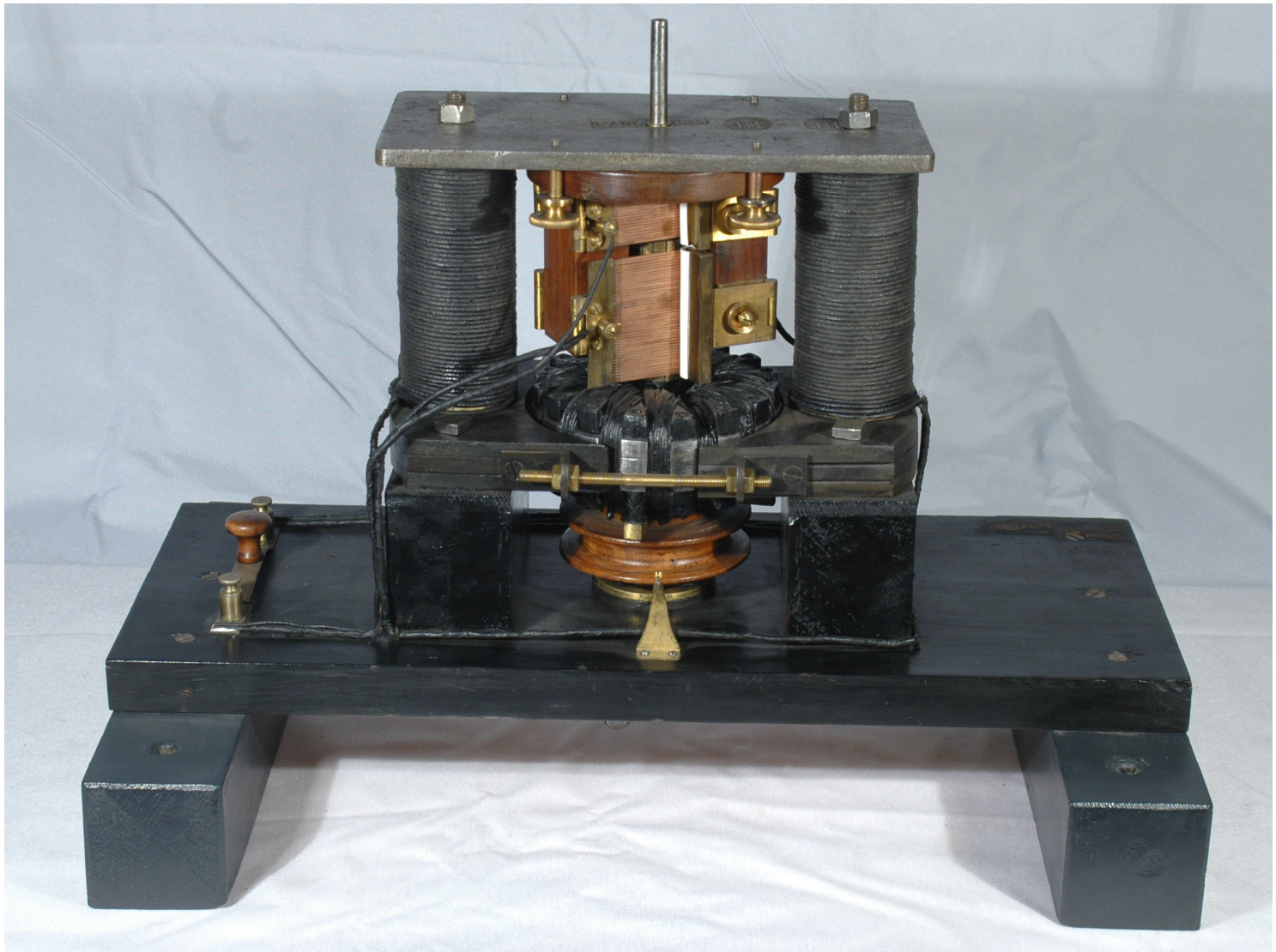


Magneto-electric machine with electromagnetic flywheel

Pacinotti believed particularly in this machine, as he considered the flywheel a stable device and able to turn quickly. For this reason he believed that a large construction of this model could have a future as an industrial machine.

Another machine that Antonio built in Cagliari was a Machine with “over-exciter”: a ring with the collector placed at the top and with a support circuit which , when activated , increases the yield of the machine. It was built in 1879, and Antonio spoke about it in the letter to the jurors of the 1884 Turin Exposition in which it was exhibited:

[...] This switch, when its thin contact layers approach it, acts as the exciter of the fixed magnet, bercause twice per turn it closes directly and it opens again a communication [...]



After the «macchinetta» Pacinotti conceived and created other electromagnetic machines, but other persons, who had independently implemented them, Patented them and exploited them at aindustrial level.

Probably this depended on the lack of interest in patents initially aroused by the gramme affair. In fact, Pacinoti began to patent his inventions only at hte end of the century.

Thus, for example, the «clew machine» was nothing else than the winding patented in 1873 by herner von alteneck. And subsequently known as «drum winding».

The same holds for the «flywheel machine»: it was exactly the «disc winding» patented in 1878and already mounted on Fritsch& Desrozieres machines.

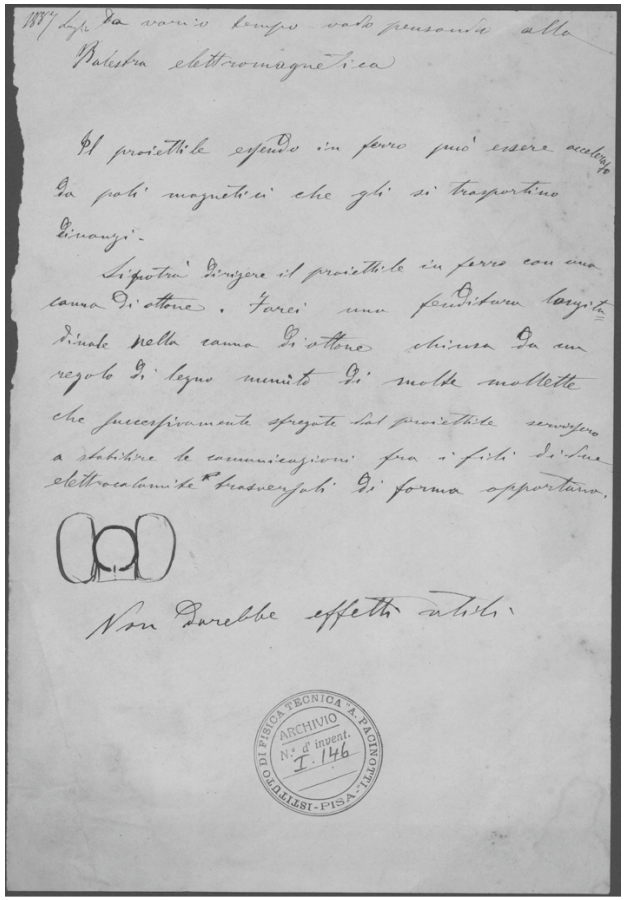
After moving to Pisa in 1882, Pacinotti never again left his hometown.

Passionate about teaching and devoted to duty until the end of his days, he held courses at the University on mechanics applied to agriculture, technological physics, rural architecture and hydraulics and finally on technological physics for mechanics applied to agriculture.

In that period he took part in several national and international exhibitions and published 28 papers concerning agricultural sciences, physics and electromagnetic machines.

He did not stop even his production of machines, for which he began to apply for patents both in Italy and abroad, but without results..

Some of his achievements at the turn of the new century (the electromagnetic traction machines) had considerable scientific and technical interest.
These prototypes realized his original idea (evidenced by an autograph document of 1887) of rectilinear displacement by electromagnetic attraction. Pacinotti patented three models between 1899 and 1901: the "electromagnetic av enue", the "electromagnetic carriageway" and the "cart with electromagnetic avenue for tramways" (These, together with their respective tracks, were possible alternatives to the train and tramway).
Despite its originality, also this new technological proposal received no attention.
As a proof of this statement, consider that in the year after the first of Pacinotti's patents, in the magazine *La tribuna illustrata* (June 24, 1900) an article appeared in which there was talk of a cannon built in America with anewly developed technology: the electromagnetic traction.


1887 Luglio Da vario tempo vado pensando alla Balestra elettromagnetica

Il proiettile essendo in ferro può essere accelerato da poli magnetici che gli si trasportino dinanzi.

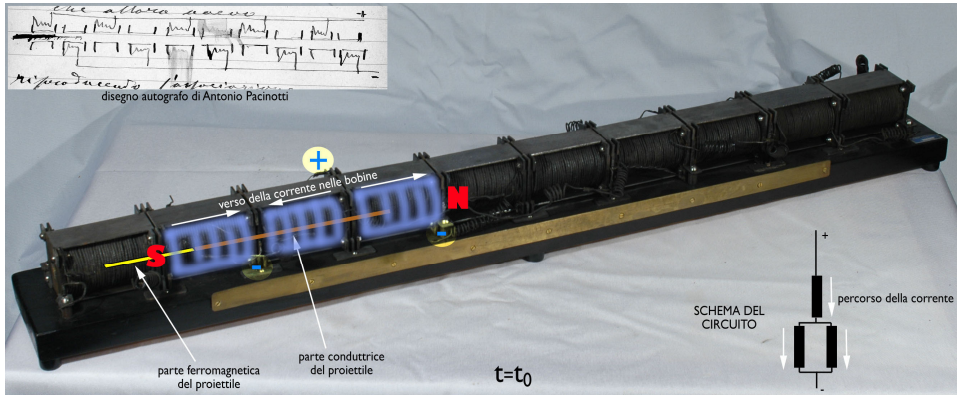
Si potrà dirigere il proiettile in ferro con una canna di ottone. Farei una fenditura longitudinale nella canna di ottone chiusa da un regolo di legno munito di molte mollette che successivamente sfregate dal proiettile servissero a stabilire le comunicazioni fra i fili di due elettrocalamite trasversali di forma opportuna.

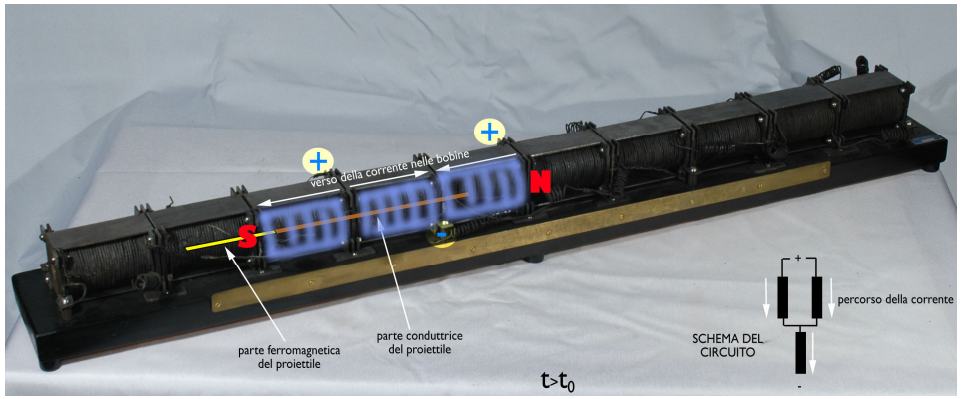
Non darebbe effetti utili.

In a note written in July 1887 we read:
[...] For some time I have been thinking about the electromagnetic crossbow
The iron projectile can be accelerated by magnetic poles transported in front of it..
It will be possible to direct the iron projectile by a brass cane I would make a longitudinal slit in the brass bar, closed by a wooden ruler provided with many pegs that, once subsequently rubbed by the projectile, could establish the communication between the wires of two transversal electromagnets having a suitable shape [...]

This is the starting point of Pacinotti's idea of using electromagnetic attraction to obtain rectilinear movement.

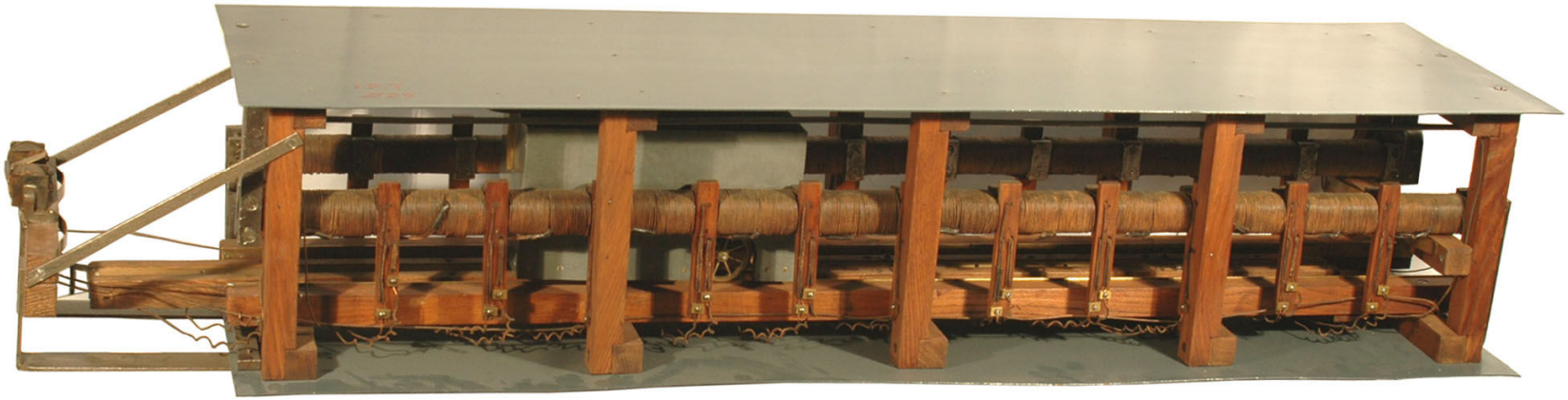
On February 21, 1899 Antonio Pacinotti presented a patent application to the competent offices of the Kingdom of Italy «Description of the invention having as its title Electro-dynamic translational machine, called Electro-magnetic Avenue». The patent was issued to him on August 11, 1899, with the number 50770.





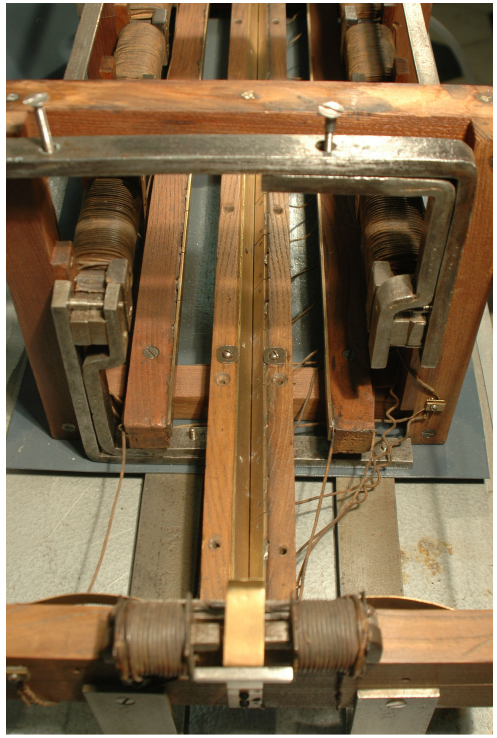
The even spools (the second, the fourth, ...) are connected to one of the poles of the voltage and to the ground while the odd ones are connected to the other pole and to the ground and the windings are wound in such a way that each spool, when the current is passing, generates a magnetic field always in the same direction. The bullet (about 30 cm long) has a brass tube at the front, with fins to facilitate electrical contact, and as a rear part an iron cylinder inserted a few centimetres in the brass tube. Once the bullet has been inserted into the avenue, as soon as its conductive front part contacts the first two coils, the current starts turning and generates a longitudinal magnetic field. By pushing forward the projectile when the ferromagnetic part enters the first coil of the Avenue, the leading conductor contacts the second and third coil and the magnetic field thus generated (which can be considered as that of a solenoid as long as there coils of the avenue) draws the bullet inside the Avenue. Afterwards the advancement of the conductive part switches the contacts between the coils so as to advance the magnetic field and maintain the attraction effect that continuously accelerates the projectile.

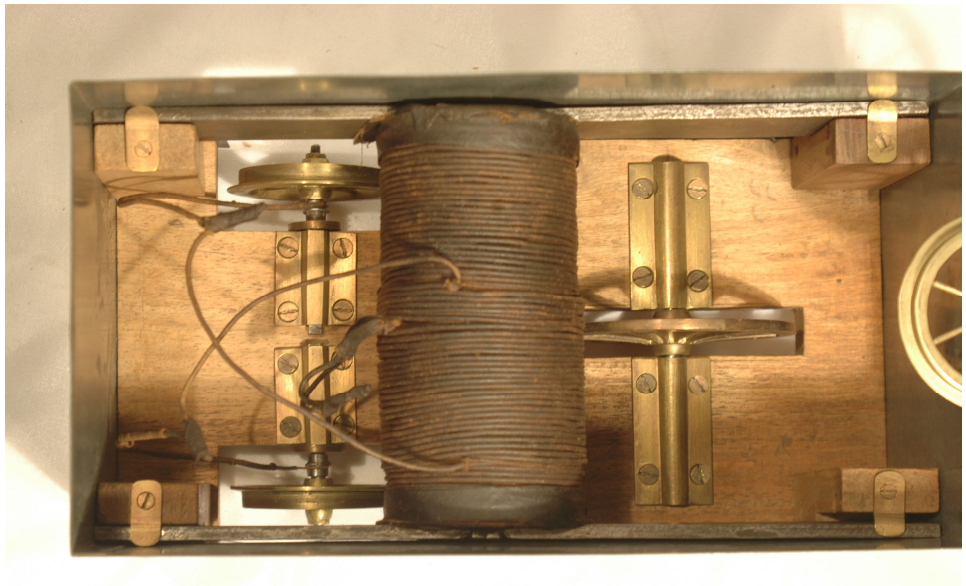
Pacinotti worked on his second electromagnetic traction machine in Spring 1899.

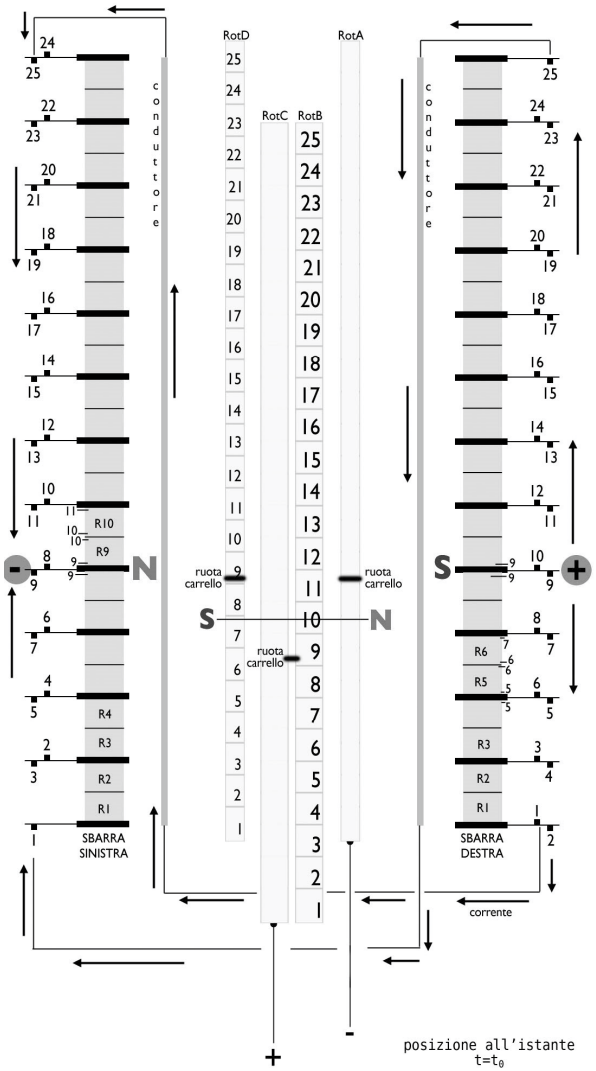


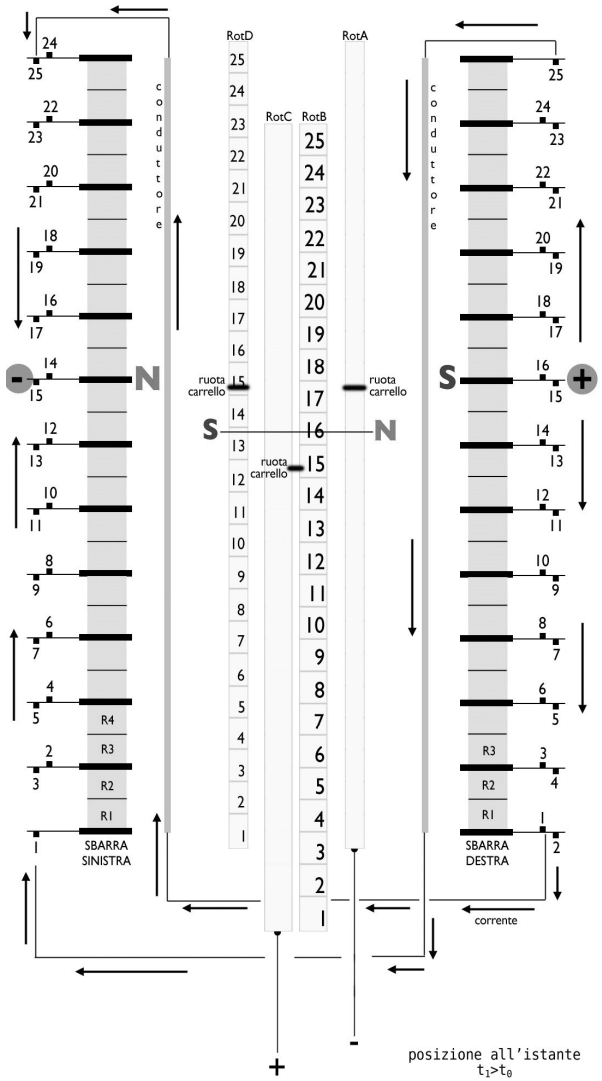
TRANSLATIONAL MACHINE WITH ELECTROMAGNETIC LACING

It is a machine that makes use of an electromagnetic avenue consisting of two sets of coils placed on the sides of the rails on which a carriage moves, whose function is similar to that of the projectile in the electromagnetic avenue









In the two figures the operation of this machine is schematised in the event that the current turns in the electromagnet of the trolley in order to have movement by magnetic attraction.

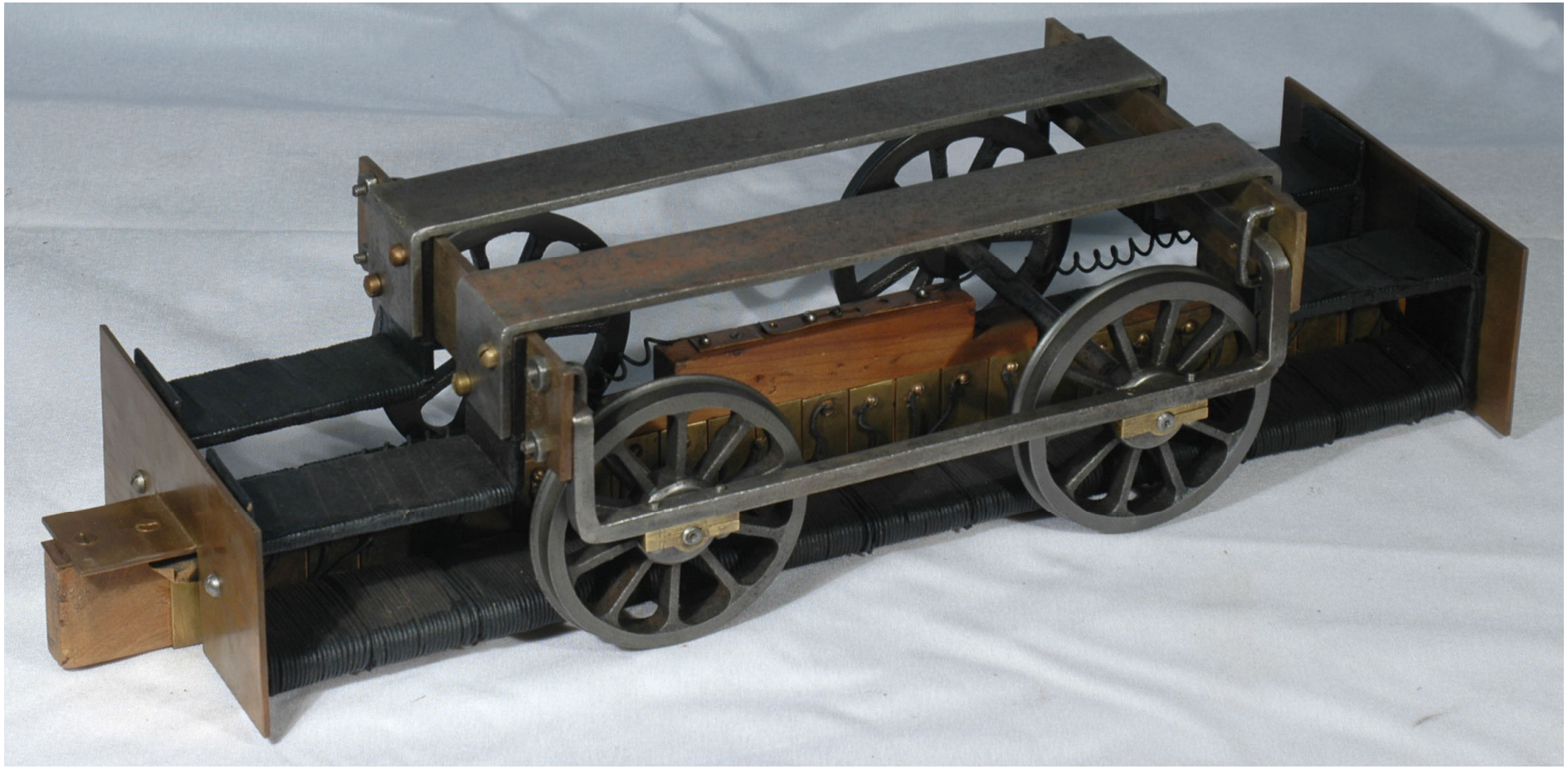
The tension is applied to the two non-sectioned rails. These are the wheels of the cart that connect these two rails with the sections of the other two; each section is connected to a wire of the side coils. In the drawing the numbers of the right rail, for example, indicate that the corresponding section is connected to the point with the same number on the right; these numbered points represent the screws that tighten the ends of the wires of the reels two by two. The same goes for the left side. Thus, the current that is established throughout the circuit produces magnetic poles on the coils that attract the magnetic poles that are created at the ends of the reel of the trolley, which consequently proceeds by electro-magnetic traction.

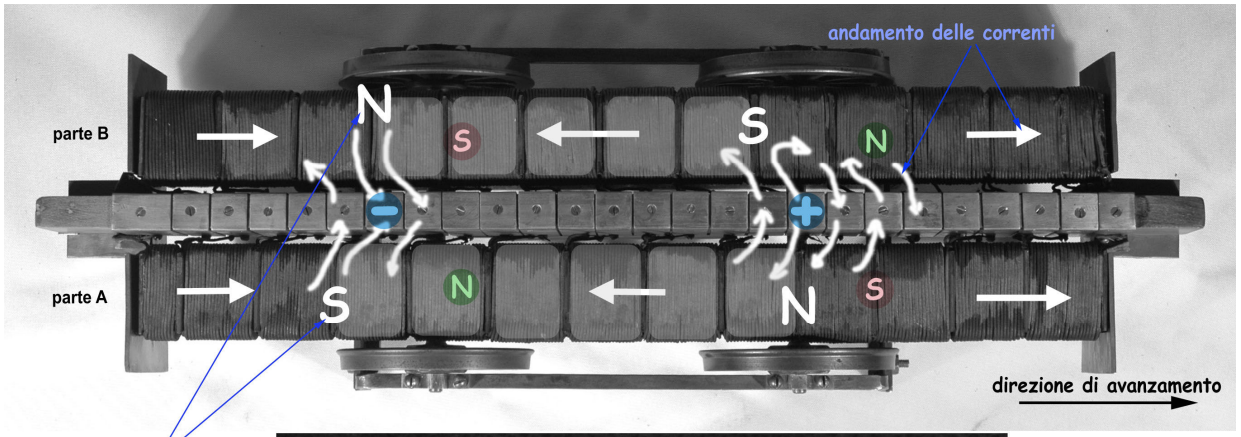
As the carriage advances, the lateral magnetic poles also advance so that the traction does not run out.

IN THIS MACHINE THE "ELECTROMAGNETIC LOOP" APPEARS FOR THE FIRST TIME: IT IS NOTHING ELSE THAN THE EXTENSION OF SOME FERROMAGNETS AROUND THE DEVICE TO CONFINE THE MAGNETIC FIELDS SO THAT THEY MAY NOT INTERFERE WITH THE OTHER PARTS OF THE DEVICE.

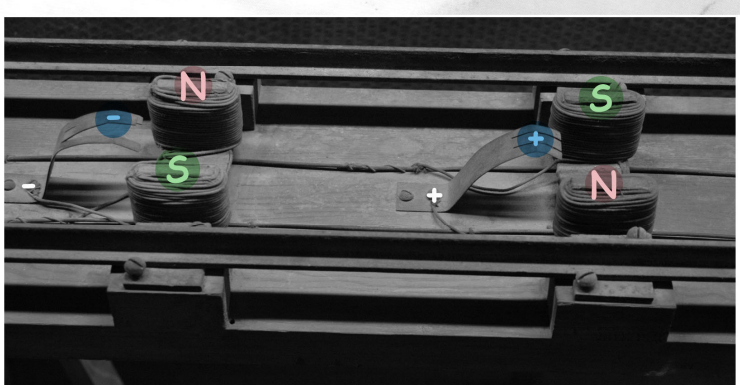
ELECTROMAGNETIC AVENUE WAGON

It is a model wagon that can travel on a track built for this purpose. Pacinotti suggested its use as a particularly useful machine for railways. The essential parts of this prototype are the lower part of the wagon and the rail sleepers. Pacinotti asked and obtained, between 1900 and 1903, the patents for this model in Italy, in Belgium, in France, in Germany and in England.



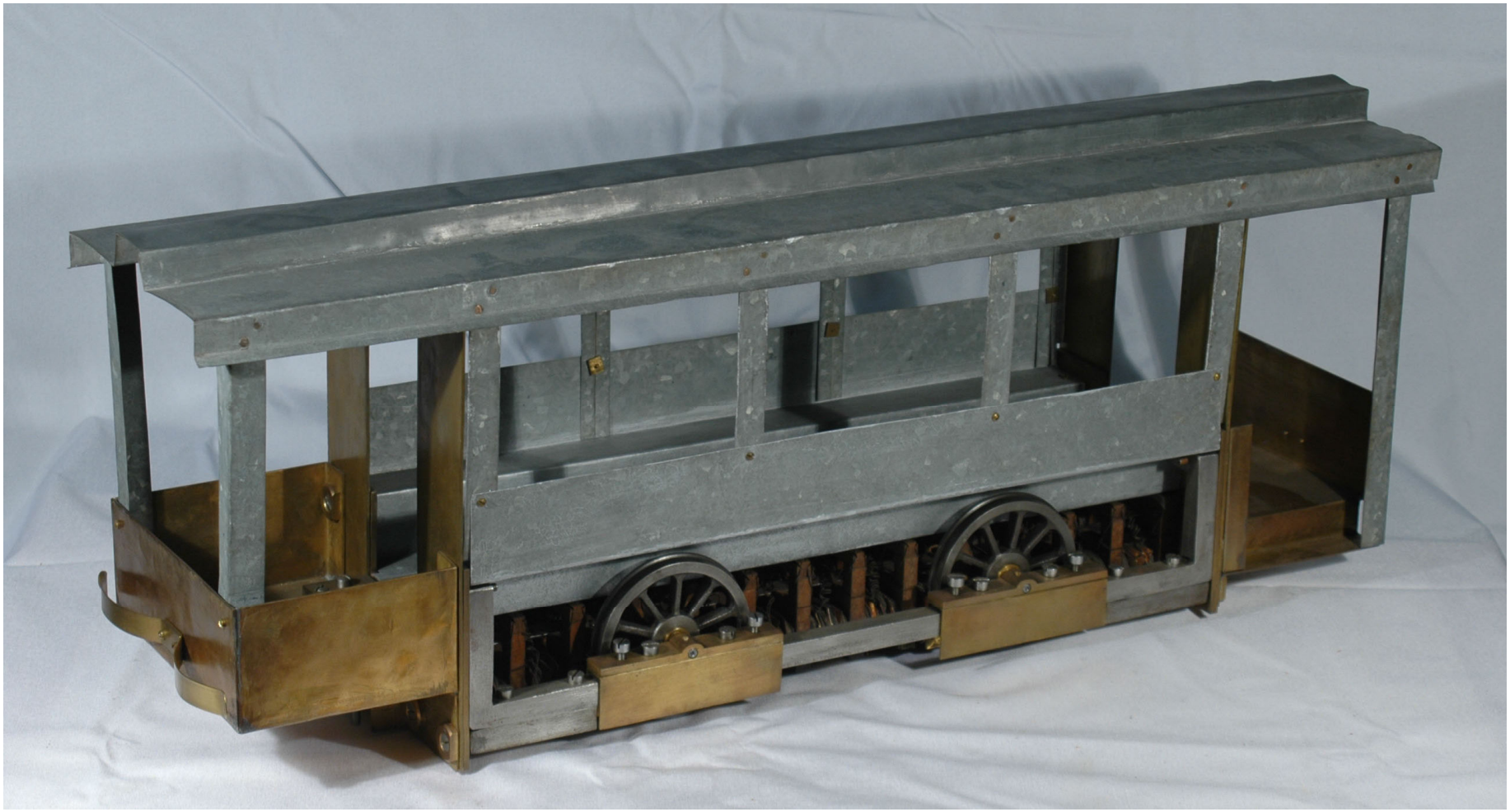


poli magnetici generati sul viale



It is as if, moving along the track in one direction, there were - transversely to the track - horseshoe magnets with poles facing upwards, arranged once in one way and one time in the other.
Since the two brackets of the avenue have a different potential, in the circuit the current biparts from the positive pole going partly to the left and partly to the right; the latter crosses the wire that passes over the upper part of the Chariot and returns to the negative pole from the left end of the Avenue. Near the positive and negative poles, magnetic poles are formed (marked with "N" and "S" without a circle), generated by the current that circulates in the spools. We tried to give a hint of the progress of these currents by drawing their path, with a sign similar sign to a brush, near the "+" and "-" poles. In this situation the magnetic poles of the vertical spools - drawn also above the avenue with the circled letters "N" and "S" – near the springs attract the magnetic poles of the avenue making the Chariot go on. As the Chariot goes on, the "+" and "-" contacts move along the avenue in such a way that the attractive effect continues; and even when a spring abandons the contact, there is already another one of the same sign that has taken its place, as shown in the figure.

CHARIOT WITH ELECTROMAGNETIC AVENUE FOR TRAMWAYS



This model of a tramway, together with its track, represents another of Pacinotti's proposals concerning the possible applications of electromagnetic traction. The operation is similar to that of the Avenue Chariot. Pacinotti obtained the Italian patent in 1902 also for this prototype.

In 1911, that is, just a year before his death, Pacinotti obtained two more patents in Italy for the Special high-potential Switch for the transverse magnet based on a composite magnetic wheel (patent issued under n.117953 on November 25, 1911) and for the Transverse electro-magnet with a breakable and recomposable ring (patent issued under No. 18772 on December 16, 1911).

On October 24, 1892, almost ten years after the death of his first wife, Antonio married the thirty-year-old Carolina Carlotta Angelini, from whom he had two sons: Antonia, in 1894, and Giovanni, in 1898.

He got several honors and academic and social appointments. Among other things he was appointed: Commendatore of the Order of the Crown of Italy (1882); corresponding member (1883) and then a national member (1898) of the Accademia dei Lincei; corresponding member (1885) and then an ordinary member (1898) of the Academy of Physical and Mathematical Sciences of the Royal Society of Naples; national member of the Italian Society of Sciences, called the XL (1886); knight of the civil order of Savoy (1888); honorary member of the Pisa Workers Society (1890); honorary member of the Institution of Electrical Engineers of London (1902); corresponding member (1903) and then an ordinary member (1906) of the Royal Economic-Agrarian Academy (the Georgofili); honorary president of the Italian Electrotechnical Association (1905); knight of the great cross (1911); honorary member of the American Institute of Electrical Engineers (1912) of NewYork.

On December 3, 1905 he was appointed senator of the Kingdom and in January 1906 he was elected councilor of the Municipality of Pisa (reconfirmed in July 1910).

In 1906 Pacinotti published four experimental works on the agricultural sciences concerning the study of the rubbing between bodies, the study of the functioning of some plows, some methods for collecting the ground and the polyspatic traction (on which he had already published in 1904). The speech given to the Chamber of Senators, in thsession of March 13, 1906, on the bill entitled "On the legal status of royal and parified secondary school teachers" should be noted.

In 1911, the 50th anniversary of the invention of the dynamo was celebrated at the national level.

He died in Pisa, in his birthplace in Via Santa Maria, during the night between March 24 and 25, 1912.

In a letter written by Pacinotti on March 30, 1911 for the university magazine "Studium", on the occasion of the tributes that were paid to him in Genoa in the Spring of that year we read:

I spent my life as a the teacher and not as an industrial manufacturer of magnetic-electric machines; but from this, it seems to me that it would not be correct to induce that I did not perceive the industrial importance of the electromagnetic ring machine, and of the clew and flywheel machines. I made and experimented the models of these machines, and I published their description and effects, precisely because they seemed to me to be industrially important. It did not come from the lack of any idea of the convenience of the machines I had proposed that I did not profit for their construction; it came from other deficiencies, at least partly not reprehensible to me.