

How They Won the Market

Electric Motors in Competition with Steam Engines, 1890–1925

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Introduction

Technological innovations usually do not appear on the market as a mature product or process. Often enough the inventors themselves are unable to anticipate correctly the purposes their ideas will eventually serve in industry. Instead, the technological potential of an idea is gradually transformed into a new industrial technology, and its function determined, by pitting it against its competitors in the marketplace.

The essential skill in engineering a successful innovation and its use seems to be to shape both the new technology and its potential field of employment in a way that the two move toward each other. In order to benefit from the full potential of a new idea, since inventive genius meets industrial demand only by accident, the two have to be organized so they converge. Outstanding innovators are distinguished by their ability to appreciate the indeterminate nature of this process, and to remain unimpressed by the characteristics of the technology and the engineers' or scientists' assumptions of how and where it should be used. Shaping a technological potential and making it converge with society's demand, which itself is very flexible, is a feat in its own right and the very point where the knowledge of the laws of nature and society meet to form technology.

Early Motors—Utopia

When the first marketable electric drives came on the scene in the mid-1800s, they were faced by the dominant steam engine and its mechanical power transmission via shafts and belts. There was little obvious need in industry for alternative drives apart

from water turbines, which ran more smoothly and gave better results in some areas, such as papermaking and the weaving of fine cloth. Reasons had to be found why electric drives could have been superior. One reason, of course, was the cost of energy; another was the spread of industry to areas that were rich in water power but poor in easily accessible sites for manufacturing plants. In Europe these sites were mostly located in the regions near the Alps. Other major potential markets, however, existed where steam was already established and electricity could hardly compete because of energy costs. Thus, in these areas electric drives only had a chance if they could bring about something that could not easily be done with steam. In the early years of electric drives, this was seen as less an economic than a social achievement—the overcoming of centralized industry and the renaissance of small businesses and craft shops.

To give just one example of this societal electroutopia of the late nineteenth century, I shall quote Werner Siemens, industrially the most successful of the inventors of the electrodynamic principle, from his lecture, “On the Age of Science,” in 1886:

Until today big machines still produce mechanical labor much more cheaply than small ones, and the erection of the latter in the workers’ dwellings is still met with great difficulty. Technology, however, will undoubtedly succeed in overcoming the obstacles to the return to competitive hand-labor by supplying the small workshop and dwellings of the workers and artisans with cheap mechanical power—the basis of all industry. A large number of factories in the hands of rich capitalists, where slaves of labor eke out their existence, is not the final goal of the development of the age of science, but the return to individual labor!¹

These views placed Siemens in the center of a broad discussion on the sociopolitical merits of the electric motor and its future employment in trade and industry.² When Siemens gave his lecture, his engineer Hoffmann had just successfully finished work on the first “dc inner-pole generator,” which could be coupled directly to a steam engine—a major breakthrough in generator technology.³ Since this new generator was working only a few minutes away in the Mauerstrasse of Berlin, supplying electricity for Berlin’s first commercially used electric motor, Siemens’ lecture was also a good piece of marketing.

In analyzing the future market, however, he was still very much caught up in utopian designs of a noncentralized and therefore socially peaceful industrial society. The kind of industry he among so many others had built up had become a hotbed of socialism. Siemens, like many other industrialists of the time, was haunted by fears that he was some kind of sorcerer’s apprentice.

In the end, of course, the conspicuous affection of the nascent electrotechnical industry for artisans and domestic industries and their—one could say post-Fordist—concepts of organizing production was not only an emanation from the widespread conservative and even restorative convictions among industrialists but very much a response to the kind of demand that was felt on the market for stationary motors. There the foremost task was to replace the all-dominating steam engine. This, however, was only likely to succeed in those fields where the mature and well-proven

principle of steam power had its conceptional limitations. These limitations were, first, the large space required for raising steam and storing fuel, and, second, the drastically rising costs per unit of power when the machine was used only sporadically. (One cannot easily store steam.) Both these shortcomings had their greatest impact in small workshops with few machines.

When electricity entered the field in the 1880s quite a lively competition already existed among the various forms of drives and motors (hot air engines, hydraulic motors, and, especially, gas motors) for the remaining share of the market.⁴ In order to win against steam power in the major industries, however, electric motors had to be more than just a miniature drive—they had to be less expensive. While this took some time, for most small workshops the possibility of any form of motor at all was already such a big step forward that the comparative quality and economy of this motor was not severely scrutinized.

Although early analysis in the electrical industry predicted little impact of decentralization upon the development of industrial society, decentralization proved to be productive and far-reaching. Research and development (R&D) strategies focused on the two weak points of steam power for small workshops: space and stop-and-go work. A third strategy, more directly aimed at rationalization in big industry, that is, the smooth regulation of motor speeds to always achieve optimum operating speeds for any machine and any process, failed almost completely. The few exceptions to this rule are discussed below.

The Shortcomings of Early Motors

While the basic engineering problems of connecting a single machine tool to an individual electric motor had been solved with the “artisans dc motor”—a small dc motor connected to the public electric light network with a short leather belt between motor pulley and machine pulley—this combination did not pass the test of industry. The weakest point was the dc motor, since it did *not* have two of the essential qualities mechanical transmissions had, and which had therefore for a long time been taken for granted in production planning and organization of labor: a fairly constant rotational speed once it was set, and a high degree of reliability even if treated carelessly.

Certainly, in both these respects the dc motor was still better than small steam engines of the same capacity, which was the reason that big industry *did* use them very early for special machines whose locations in the factory were isolated and that had to have some form of individual motor.⁵ But these heavy machines were operated by highly qualified personnel, who were best equipped to cope with irregular speeds and delicate apparatus, since this was not so different from their experience with individual steam drives. Moreover, these specialists did appreciate and make intelligent use of the possibility of being able to continuously regulate the motor’s speed.

At these specific points of production it was not so much the ratio between labor-plus-capital-cost per kilogram of output that was decisive, but instead the uniquely large variety of possible ways to shape a product. In these places it was already profitable, *if* one could do it; energy and labor costs were of secondary importance. This somewhat resembled the situation in the crafts, so it is not sur-

prising that individual electric drives spread first in those departments that resembled craft production, that is, isolated, highly qualified, and producing small batches.

Mass production, however, was quite “uncraftsmenlike.” The prime object was a high rate of standardized products per unit of time, which did not encourage the semiskilled piece-rate workers to be overly patient with their machinery, or least of all to be careful when correcting irregularities in machine operations. The problems of the steadiness of rotational speed and the proneness to breakdowns therefore multiplied in the big workshops.

On one hand, the machine tools, looms, etc. used in mass production were usually smaller and weighed less than the separate electrically driven special machines, which made it harder to keep them at a constant working speed. After all, it had been one of the prime virtues of central transmission that it compensated for sudden peak loads with the enormous inertia and the great number of elastic belts the machines used.

On the other hand, the well-proven belt drives were quite resistant to ruthless treatment. If overloaded, they simply started to slip, thus producing a squealing sound that warned the operator in time to save the machine and the product from serious damage. Electric motors, however, continued operating, producing a bit of extra warmth and a pungent smell that came too late to be effective warning signs.

In practice, the most dangerous moments for electric drives were—and still are—the first seconds after being turned on with a load. After that, the most dangerous times were short time peaks or overloads. As a result, many workers never voluntarily turned off their machines when mounting new tools or workpieces, but let them run permanently like a central transmission. This, of course, made all calculations of energy savings with individual electric drives worthless. It was particularly true of small motors, which had an efficiency of about 75 percent, a rating that did not compare favorably with a central transmission.⁶ But even then there were still the many costly breakdowns of overloaded motors.

Similar problems existed in the textile industry. In 1894 in Mittweida, Saxony, the first cotton-weaving factory to be equipped with individual dc electric drives paid dearly for its pioneering spirit.⁷ Only a year after installation the whole factory had to be converted back to central transmissions, since none of the early hopes and promises had materialized. First, the service costs for the 600 loom motors were much higher than they had been with steam and shafts. Since weaving looms have to start very quickly under full load to prevent visible shadings in the cloth, the 600 motors were necessarily and constantly ill-treated and failed accordingly. Shunt-wound motors, which had to be used since they have a relatively constant rotational speed, unfortunately produce a fraction of their torque only when started, and therefore require a careful starting procedure to prevent them from overloading. In weaving, however, as in many other industries, this is the very moment when maximum torque is required. Hence the temptation to abbreviate the starting procedure was irresistible to the workers. Second, fuel consumption for the power plant was greater than it had been for steam only—no one stopped the motors during breaks contrary to what had been assumed in the cost estimates. And, third, because the electric plant cost much more than a comparable steam plant, losses occurred in all three major accounting areas: output, operating costs, and capital costs.

Identifying the Problem

Almost until the turn of the century the electric motors offered by manufacturers were influenced more by what was possible to do “by electricity” than by industry’s production needs and traditions. Since only electric motors were usually “employed,” the search continued for new possible applications for a given electric motor technology. If treated carefully by trained personnel or a cottage worker or artisan who had put his own money into the motor, these early dc-driven machines—from the variable-speed turning lathe, with its huge headstock motor, to the cottage weavers’ ribbon loom, which was connected to the local electric light company—worked properly and in some respects quite impressively.⁸ But just as artisans and cottage laborers in general could not withstand the competition from mass production, these motors could not hold their own against steam, shafts, and belts. For both dc motors and artisans there were only niches left in the market.

The breakthrough, as is well known, was brought about by the development of the asynchronous polyphase motor after 1888/1889. This motor, especially the squirrel-cage type, was put on the market in greater numbers at the turn of the century. By no means, however, were all problems solved by this “ideal” motor.

The *small* polyphase motor also began to be used where it could be employed unmodified, which meant with high and constant rotational speed. The 2- to 4-pole types of between 1/10 to 3 hp could not run at less than 2800 or 1400 rpm (with full load) on a 50-cycle ac motor. Not surprisingly, from the early 1890s technical journals were full of advertisements for polyphase centrifuges (separators!) and ventilators.⁹ The high number of rpms of the small polyphase motors were the very obstacle to their use with machine tools or looms, which were designed to run at 20 to 300 rpm.

While in principle one could overcome this problem with the help of a belt or toothed back gears, these machines did not last too long because of the lack of experience with fast rotational speeds. Leather belts posed another restriction in that even the best material could not undergo more than 12,000 bendings (180°) per hour before it gave out from fatigue.¹⁰ A 2-pole motor with a 12-cm pulley attached to it would have required a belt 11 m long (5.5 m with a 4-pole motor). Synthetic cone belts, which today solve this problem very well, did not appear in central Europe until the late 1920s, when an Italian engineer began production under American licenses.¹¹ At the turn of the century the only recognized solution was the toothed gear. But here, too, experience in its use was scarce.

In transmission technology, late 19th-century engineers had had to make do with peripheral gear speeds of between 2 and 3 m/sec.¹² With a 2-pole polyphase motor and these slow perimeter speeds, the diameter of the first gear could not have been more than about 2 cm! (Fifty cps for a 3-m perimeter = a 6-cm perimeter per revolution = a 2-cm diameter.) Realistically, one had to come to grips with perimeter speeds that were three to five times faster before one could entertain the idea of directly coupling a small polyphase motor to a machine tool.

Since turn-of-the-century manufacturers of machine tools weren’t much interested in the problems of individual electric drives, the electric manufacturers had themselves to take up the development of small and inexpensive high-speed gears.

The pioneering work in matching small fast-running polyphase motors to slow-working machine tools via toothed gears in Europe was done by Otto Lasche, head engineer of the Allgemeine Elektrizitäts Gesellschaft (AEG). Lasche commenced his thorough R&D program on fast-running gears only a few months after his company had converted large portions of its workshops to individual electric drives with polyphase motors of between 960 and 1440 rpm and belt drives.¹³ It is of some importance here to mention that these motors were by no means the cheapest and simplest of their size, but were rather expensive multipole models, since they had to be slow enough for the belts! But obviously they weren't.

Having affirmed the robustness of his company's polyphase motors, and having complained about the many breakdowns in practice, which according to him were in most cases due to the failure of the connecting links between motors and machines, Lasche proclaimed the following as the future task of R&D:

To do without separate links (between motor and machine, UW) is impossible; neither can an electric motor be produced at competitive prices with the slow speed required, nor is it feasible to increase the speed of the machine tool for the benefit of the motor. The demand of practitioners for slow running power shafts is quite irrefutable and points to the necessity of back gears, and in fact toothed-wheel back gears to be sure.¹⁴

Lasche's work was unique in that he was the first to deliberately turn away from his own field of electrical engineering to solve the problems of electric drives. He did not see the future of the electric motor to be its versatility, which called upon the imagination of so many electrical engineers, but in its inconspicuousness. To enter the big market one did not need to show factory management what one *could do* with electric drives, but rather show what *did not happen* with it. Or in other words, the motor had to be a troubleshooter, not a wizard.

Back Gears

Lasche's basic work on fast-running back gears had discovered the main trouble point of individual electric drives and had paved the way for the future development of gearbox technology. In overcoming the problems of the fastest speed and greatest transmission ratio first, he had created the best preconditions for a further division of gears, even if this potential was not fully exploited until the 1920s. Until then gears were largely used only to reduce the speed of the motor to the speed required by a normal belt-driven loom or lathe.

For those machines that only had one constant working speed, all the basic problems were now solved. This is true for many parts of the textile industry, where polyphase plants with individually driven weaving looms became the rule shortly after the turn of the century.¹⁵ Here again it is important to stress that the spread of individual electric drives in general owed less to savings in power costs than to the increased productivity of a given machine. It was this increasing demand that made mass production of small induction motors possible and triggered off a massive slide in prices. One-horse-power motors, which cost 450 marks in 1900, were available in 1908 for 160 marks in Germany.¹⁶

TABLE I Distribution of the Costs of Production in the Textile Industry

	English Textile Industry (1) (%)	Cotton Spinning (2) (%)	Cotton Weaving (2) (%)	Cotton Spinning (3)			Cotton Weaving (4)	
				No. 40, 1913 (%)	No. 36, 1925 (%)	No. 20, 1913 (%)	1905 (%)	1925 (%)
1. Power and fuel	1.3	1.5	1.5	3.5	3.5	2.1	4.0	2.8
2. Raw materials	57.0	68.1	64.9	64.0	54.0	72.5	60.0	72.0
3. Wages	19.7	11.2	15.2	8.0	5.8	7.3	10.0	4.8
4. Other charges and profit	22.0	19.2	18.2	24.5	36.7	18.1	26.0	20.4
Total Percentage	100	100	100	100	100	100	100	100

Weaving Looms

If one takes, for example, the distribution of the costs of production in the textile industry, one can see that the proportion of power and fuel costs was of the order of only 1.3–4.0 percent of the total production costs (see Table I¹⁷). From this it is clear that even a very considerable saving in power costs can have only an infinitesimal effect on the price of the goods and the profit. Even a power saving of 20 percent would, if it could be obtained free of cost, only increase a 10 percent profit to something between 10.26 and 10.80 percent of the original amount. If against this we consider the effect of an increase in the quantity of production on the net profit, we obtain a totally different picture. A 10 percent increase in production due to individual electric drives, again in the textile industry, could typically increase an existing profit of 5 percent to 7–9 percent, and an existing profit of 15 percent to 17–19 percent. These figures were found in cost assessments in textile mills in the United States, England, and Germany between 1910 and 1920.¹⁸

The higher turnout of a given loom due to individual drives resulted from reduced variation and fluctuation of the working speed.¹⁹ Figure 1 shows what happened with a conventional line-shaft transmission. In order not to exceed the maximum speed of the looms (spinning or weaving), the whole transmission had to run almost 10 percent slower than optimum speed because of the speed variations in the last row. It was said that it was impossible to operate some automatic looms under these conditions, and visible shadings in the cloth from normal looms meant cloth of an inferior quality. The same is true with spinning, although to a lesser extent.²⁰

The main point I want to make here is that the introduction of individual electric drives was not just another form of energy, but a new approach to production technology. Electricity won the day not because it was cheaper, but because it enabled engineers to make a more sophisticated and more flexible use of motive power.

Machine Tools

A somewhat different situation than in textiles, however, prevailed in metal cutting. Here there wasn't one well-defined optimum speed, but a large number of different speeds required for cutting steel of various diameters, etc. And as the tech-

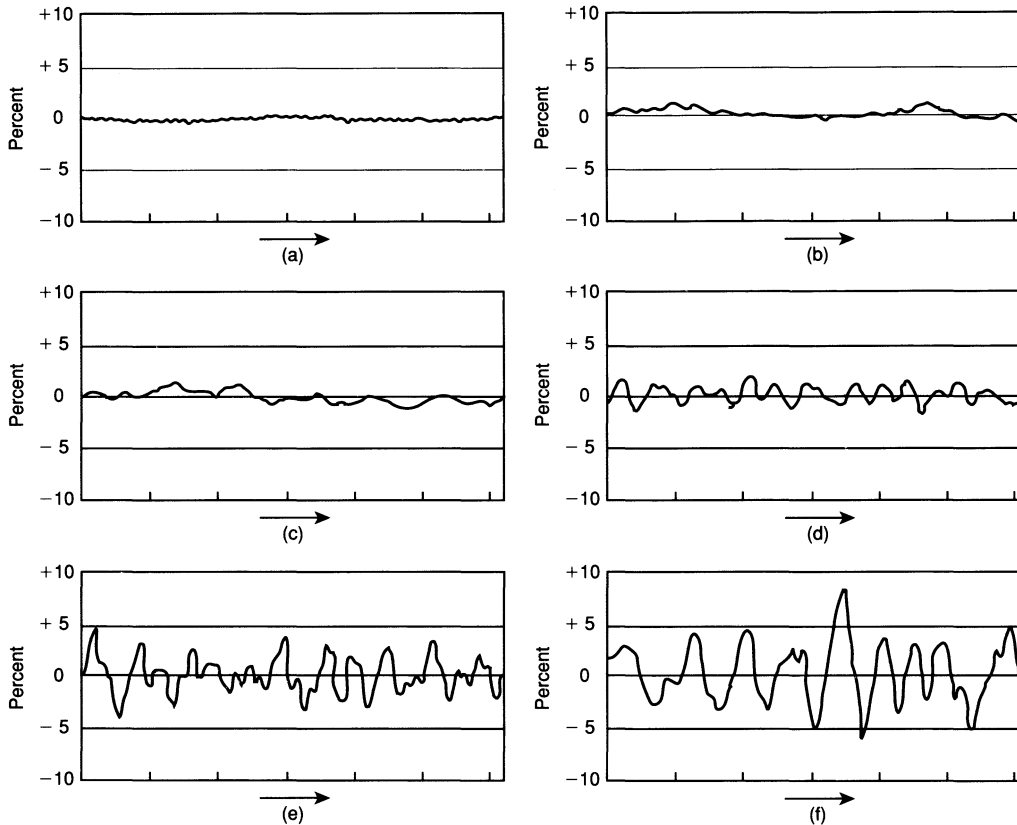


Figure 1. Speed tests on line shafting a jute weaving mill: (a) speed at the beginning of the main shaft; (b) speed in the center of the main shaft; (c) speed at the end of the main shaft; (d) speed at the beginning of the 13th group shaft; (e) speed in the centers of the 13th group shaft; (f) speed at the end of the 13th group shaft.

nology of cutting steel changed during the period from the late nineteenth century to the mid-1920s, the number of speeds required of a turning lathe, for example, also increased. At first glance, this seemed to make variable-speed dc-powered lathes more attractive at last, and a large number of designs for individually driven turning lathes with a dc headstock motor were advanced. With these motors it was, in fact, very easy to meet the demand of a narrow sequence of rotational speeds with steps based on $^{10}\sqrt{10}$ or $^3\sqrt{2}$, respectively ($= 1.26$).²¹ Indeed, these machines would probably have been as successful as expected if it weren't for the small dc motor's speed variations under a changing load and semiskilled piece-rate work, neither of which the work force was experienced or patient enough to cope with.

In qualified hands, and without the pressure of time, these machines did their job admirably well and were the marvel of all engineering exhibitions. Still in 1926 the then most recent model of a dc headstock-driven turning lathe was presented by the manufacturer (Boehringer) to the *Deutsches Museum* as their most remarkable feat in machine tool design. And in a way it was, this model being

a good example of the large disparity between engineering and industrial values. Industry did not buy these “marvels” in great numbers, however, but, until well after World War I, followed the more trouble-free path of electrification via group drives with big and medium polyphase motors (50–100 hp) or else stuck to steam engines.

Like Lasche before them, engineers in the electric industry or electrical engineers involved in machine building could only slowly overcome their belief that one should do “by electricity” what could be done “by electricity.” It was obviously not easy for them *not* to use the inherent potential of electric drives—that is, adjustability—only because “uneducated” and impatient piece-rate workers continued to wreck their engineering marvels or were incapable of making intelligent use of the technologically elegant continuous-speed variation at their disposal.

The Motorized Machine Tool

Whether it was favorable circumstances (i.e., cutting-steel research simultaneously making enormous progress) or whether it was the eventual insight that production organization and the characteristics of shunt-wound dc motors were incompatible may be open to debate. Whatever the reason, developments in machine-tool design after the turn of the century focused more and more on the small polyphase squirrel-cage motor with a back gear.

The most important innovation at that time was, of course, the higher cutting speeds made possible by Taylor’s high-speed steel and similar alloys. These developments not only meant an increase in turning speeds, but also an increase in the power transmitted to the headstock. Given the usual space constraints, the traditional belt drives now came under pressure from two sides: power and speed. A third severe limitation was caused by the demand that the universal turning lathe have at least 16 different speeds. While one could easily transmit more power with a belt by increasing its cross-sectional area—preferably its width—a thicker or wider belt made shifting gears more difficult. What should a leather-belt gear box for 16 speeds and 10 hp look like?

To cut a long story short, independent of the development of electric drives, engineers in machine-tool design shifted from few belt gears to a great number of toothed gears to achieve both the transmission of more power and a narrower ratio of speeds. The result of these efforts was the single-pulley turning lathe with an integrated gearbox.²² Since the belt was no longer used to switch gears, it could now be made wide enough to transmit the necessary power from the line shaft to the one remaining pulley. It made little difference if this main pulley was driven by a belt or by an electric motor with back gears, as long as the back gear ran smoothly enough not to cause chatter marks on the workpiece.²³ It was no longer enough to have just any old back gear, as, for example, with weaving motors, but now a high-quality gear was required, especially if it were to be used for metal working.

After the mid-1920s all major manufacturers of machine tools equipped their lathes with an integrated gearbox that could be driven according to the specifications of the client, either by a belt or by a flanging motor. The machine tool remained the same whatever the power source. The move to standardize as many components of a machine tool as possible also helped make the polyphase motor more desirable than the dc drive.

Since in the 1920s the machine tool industry designed its gearboxes for the largest market, which was still line-shaft driving, it had to provide for the whole range of 16 to 18 gears. Once the problems of the 16-gear gearbox were solved, it was no longer financially viable to offer a simplified version for dc motors, where the adjustability of the motor would provide for, say, 12 of the 16 gears. To combine dc motors with these new gearboxes to achieve even finer steps between the 16 or 18 gears did not pay, since there was hardly any noticeable productivity gain with steps of less than $10\sqrt{10}$. Moreover, mechanically shifting gears had the great advantage of being precise and reliable. Direct current motors remained what they always had been since the 1890s: expensive exceptions for use in the occasional unconventional machine.

First Conclusion

To state my first conclusion: It was progress in tooth construction and gearbox construction that, beginning with the critical point of fast-running back gears, eventually paved the way for the small polyphase motor to become the universal source of power for individual drives in industry. The electric industry's own contribution—apart from the motor itself—was pinpointing the motor's high speed as the weak spot and then designing a robust mechanical coupling link to reduce the rotational speed instead of insisting on adjusting the electrical current. These manufacturers were lucky, however, that their correct but incomplete engineering strategy coincided with a congenial strategy in machine-tool design that was based on progress in cutting technology. The electrification of the engineering industry was not just the adoption of electric motors, but resulted more from the shaping of a new synthesis of mechanical power and machine operations. In other words, it was only as a part of this new synthesis that the electric motor was universally adopted in industry.

But before electrification could succeed, the industry had to realize that what could be achieved through technology was relatively unimportant and that what was really essential was that these new motors accommodate the ways in which industrial production was organized. The exception to this insight was continuous-speed regulation through automation. This analysis is also supported by the important exceptions to the rule of the nonuse of continuous-speed regulation with electric drives. Apart from various forms of transport,²⁴ the most notable of these exceptions are to be found in the steel industry, paper making, and spinning.

Rolling Mills

Although among the first industries that built their own electric plants to make use of most waste heat and waste gases, the steel industry was particularly reluctant to adopt electric drives for use in rolling steel, the process that required the most motive power. In fact, so congenial was the steam engine to these erratic power demands that the rolling crews could barely conceive of using any other type of motor.

On the other hand, the general managers, who were interested to find ways to utilize, without extra cost, the huge quantities of gas and heat a steel plant produced

as a by-product, were more open to other alternatives. Since heat is difficult to transport, their first attempt to get more out of these by-products was to use big gas motors in the rolling mills.²⁵ This experiment ended in complete failure, since the gas motors had no torque when they came close to a standstill, which resulted in many blocks being wasted or at the least needing to be reheated for a new try.

With the failure of gas engines, the managers turned to electric motors as their second choice, but even so, these motors often entered through the back door. Rather than starting them off at the huge roll stands of reversing mills, where the many-thousand-kilowatt Leonard drives (German: Ilgner-Umformer) were later employed,²⁶ electric motors were first widely used to drive the life rollers, which transported the steel blocks from one roll stand to the next. This was a simple task since, unlike their resistance to the forming operation under the rolls, the weight of the steel blocks could be easily measured. Electrically driven systems, unlike those powered by gas motors or steam engines, had the advantage that their rollers could be controlled from a good viewpoint, distant from the motor itself. Very often, slightly modified electric tramway motors were employed, and they soon became widely used throughout the steel plants to transport materials over roller tables, across tilting tables, through various manipulators, and vertically by cranes, which also used tramway motors.²⁷ These motors included a most important feature: an automatic contactor control that made it difficult to ruin them (see Fig. 2²⁸). This

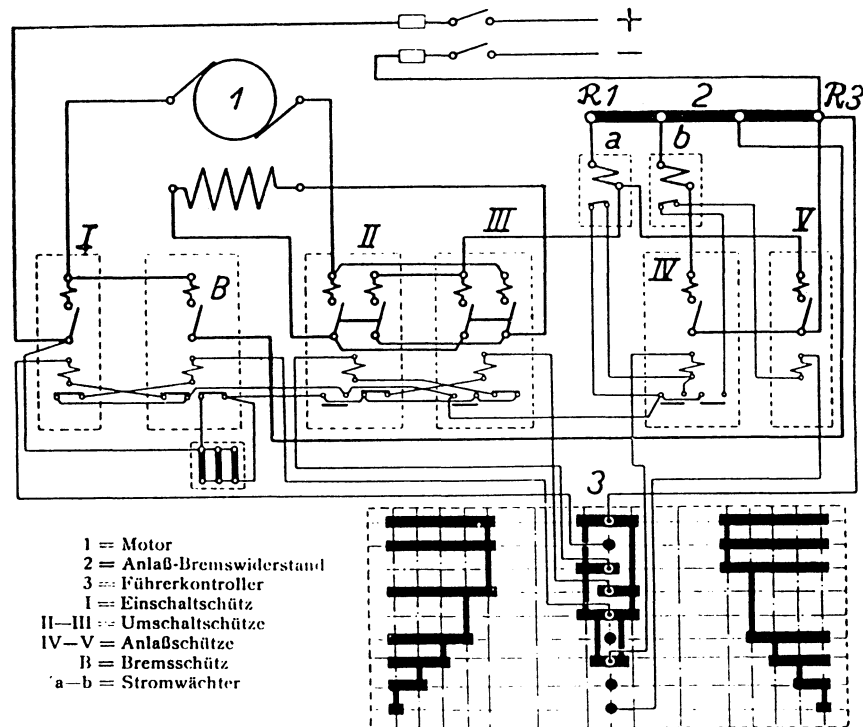


Figure 2. Wiring diagram of an automatic contactor controller for rolling mills. 1 = Motor—motor; 2 = Anlaß-Bremswiderstand—starting resistor (rheostatic starter); 3 = Führercontroller—master controller; I = Einschalterschütz—starting contactor; II-III = Umschalterschütze—switching contactor; IV-V = Anlaßschütze—accelerating contactor; B = Bremserschütz—breaking contactor; a-b = Stromwächter—contactor.

automatic safeguard was too expensive for the small weaving-loom motors of 1/8 or 1/4 hp, but compared with the price of a several-horsepower tramway motor, the cost was bearable, and the almost foolproof motor won many markets other than street-cars. In a way it was an incomplete though sufficiently successful electric simulation of an ordinary steam engine. Steel managers were delighted that the great number of “little steam squanderers”²⁹ all over the vast areas of their steel mills could be replaced with something as rugged and easy to handle.

From Automatic Controls to Semiautomatic Drives

If the idea behind these automatic contactor controls was to protect the motor from fatal currents and still give the operator the feeling that he could get the motor's peak performance whenever he wanted, it also opened the electrical engineers' minds to the idea that the current could be used simultaneously as both a source of power and a carrier of information. This new insight led from using some form of automatic control to protect one motor to protecting a whole set of motors. For example, if the motor's own current could be used to protect it and control its power, why not use the current of another motor to control the speed and direction of the first? Life rollers usually transported steel blocks between roll stands, so motors in roll stands would always have to work close to or at their maximum output. This was as precarious with electric motors as it had been with gas motors, since both lack torque below their normal operating speed. The optimum solution was a life roller that fed steel only at the rate the motor of the roll stand could handle. This was achieved by controlling the life roller through the main motor of the roll stand (see Fig. 3³⁰). A low current in the main motor would speed up the life roller; a high current would slow it down; a critical current would reverse the life roller and thus pull the steel out of the overloaded roll stand. The same control devices were used for many similar situations in industry, for example, in sawmills.

This semiautomatic roll-feed control both protected all the motors and still guaranteed best possible performance of the whole arrangement. This advance at last gave electric motors in rolling mills a clear advantage in productivity over steam engines while matching their reliability and ease of handling. Again, as with gearboxes, the crucial role of automation was not the creation of versatile and sophisticated engineering marvels, but the reduction of risks on the shop floor.

Spinning Motors

Automation or rather semiautomation, discussed in the second example below, was also a key to success. Spinning, like weaving or cutting metal, is a process that should be done at a single optimum speed, that is, the tension of the yarn to be spun has to be constant and close to the breaking point in order to get good quality and maximum output. An additional problem with spinning, however, is that the quickly produced yarn has to be wound onto a cop whose diameter changes rapidly and considerably in the process. To keep the speed of spinning—and with it the tension of the yarn—constant, the rotational speed of the cop has to vary. The same problem

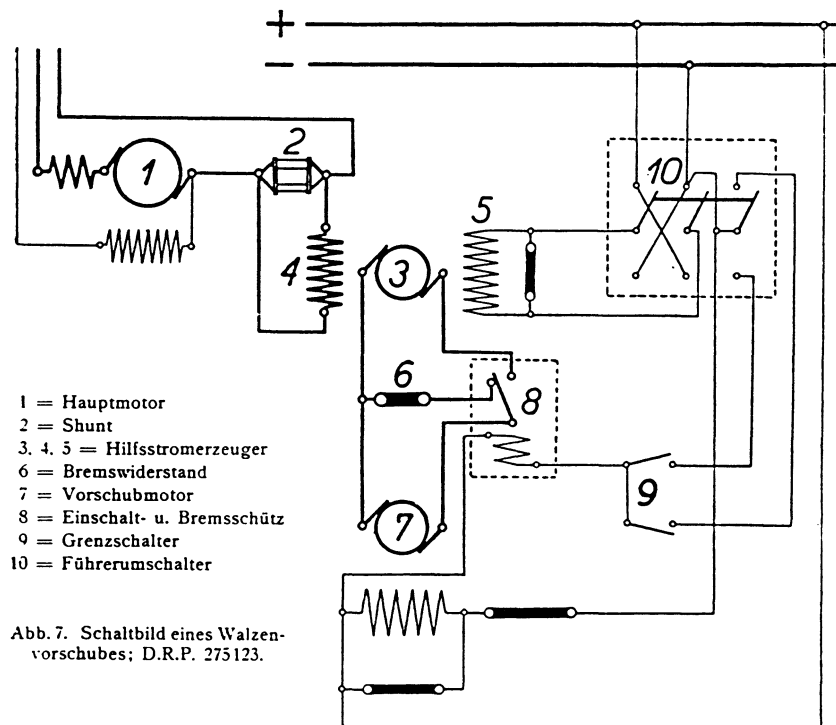


Figure 3. Wiring diagram for a feeding roller. 1 = Hauptmotor—main motor; 2 = Shunt—shunt; 3, 4, 5 = Hilfsstromerzeuger—auxiliary current device; 6 = Bremswiderstand—break resistor; 7 = Vorschubmotor—feeding motor; 8 = Einschalt- und Bremsschütz—starting and breaking contactor; 9 = limit (stop) switch; 10 = Führerumschalter—master controller.

occurs with papermaking, where the moist and soft paper has to be wound under constant and well-controlled tension. Since the motor characteristics required for these processes are the same,³¹ I shall limit my short presentation to spinning motors.

The speed of the spinning machine is limited by the amount of tension the yarn can stand. At a given speed this tension is highest when the balloon is large, that is, when the bottom of the cop is built (see Figs. 4³² and 5). With mechanical transmission and only one speed, the spinning frame would continue to run at the low starting speed for about 90 percent of the spinning time. A two-speed gear improved the situation, and was often used (see Fig. 6³³).

But after the bottom of the cop was built, the tension of the yarn in the balloon was not constant, but changed with the level of the ring bank. This gives the curve in Fig. 7³⁴, which was impossible to achieve with mechanical gears.

A smooth curve for the spindle speed could only be achieved at a reasonable price with the electric motor. Once this was achieved, engineers asked why not go a step further and also allow for the speed variations in building every single layer of the cop? This curve would look like that in Figure 8.³⁵

Summing up the productivity gains of these four steps measured in output per spindle would yield an additional output for a given machine of about 20 percent, 13 percent of which came from the speed variations of individual electric motors.

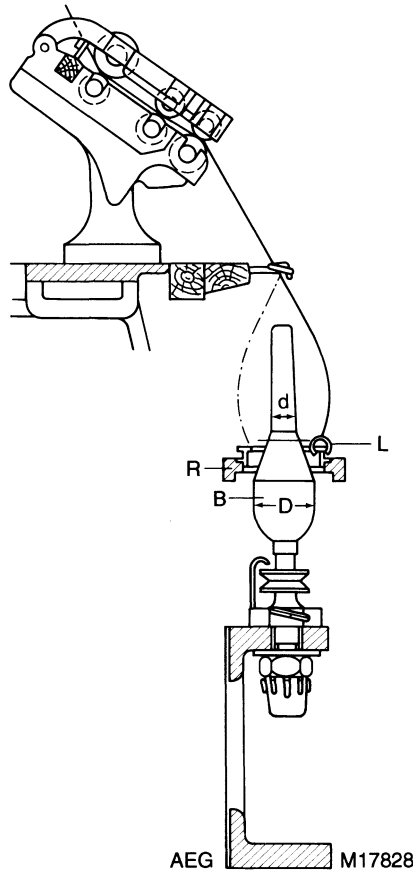


Figure 4. Diagram of a spinning machine. B = Kötzer-cop; D = Kötzerdurchmesser-cop diameter; L = Läufer-runner; R = Ringbank-ring bank; d = Hülsendurchmesser-tube diameter.

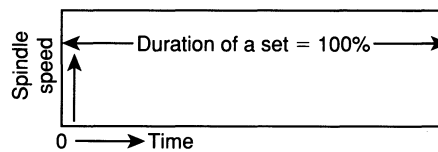


Figure 5. Line-shaft drive.

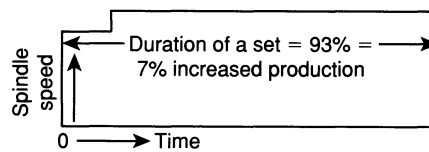


Figure 6. Line-shaft drive with second speed for building up the base.

The only problem left was how to govern the speed of the motor to follow this ideal curve. There had to be an additional element between the ring spindle and the motor to allow the position of the yarn on the cop to regulate the motor speed. And as with the back gear, in order to create a new market for their products, the elec-

Figure 7. Electric individual drive with spinning regulator for the basic speed.

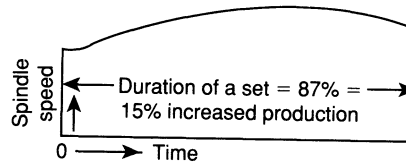
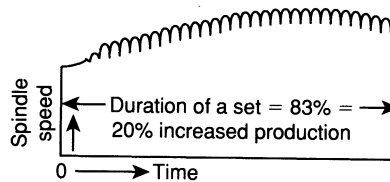


Figure 8 Electrical individual drive with regulator varying the spindle speed for each layer of the cop.



trical manufacturers were determined to find a solution to this problem. They tested dozens of ring-spindle machines, using stroboscopic light and sophisticated measuring equipment, which they had developed. The result of this R&D in the spinning process was the spinning regulator, a purely mechanical device that used the shifting level of the yarn, and consequently the shape of the cop, to adjust the rheostat that controlled the motor speed.³⁶

Second Conclusion

The motors that were eventually designed for these spinning machines in the 1920s—like the papermaking machines, which had similar characteristics—were a combination of a dc and an ac motor, and were polyphase commutator motors (a polyphase stator with a dc rotor).³⁷ They were universally adopted in paper and textile mills, but not for machine tools, for which they were heavily advertised as an improved alternative to the ill-fated dc motor.³⁸ The reason for their success in the textile industry was that the ring-spindle machine had one single well-defined speed curve that could be governed by an automatic device, the spinning regulator. Speed regulation could be designed once and for all into the hardware, and was not left to the judgment of an unskilled or at best semiskilled worker who, for many reasons, might be tempted to act differently than foreseen by management, or might not even be able to assess and control the speed of his spinning machines as precisely as an automatic system could.

Where automatic devices, such as the spinning regulator, would not work because of the nonuniformity of the product and the frequent mounting of new workpieces, as in cutting metal, tables and written orders with specified speeds that came close to the optimum prevailed, rather than efforts to improve the skill or to increase the responsibility of the workers. Especially after the arrival of mass production, predictability was paramount among managements' concerns. Automation, tables, and "foolproof" machinery were ways of achieving it. A technology that required individual and spontaneous judgment on the part of the operators might have appealed to engineers, but it certainly did not to accountants.

Notes

1. Werner von Siemens, "Das naturwissenschaftliche Zeitalter," in Werner Siemens, *Wissenschaftliche Abhandlungen und Vorträge*, 2nd ed. (Berlin, 1889), pp. 491–499, especially pp. 498–499.
2. For a detailed account of this discussion and the introduction of electric motors in small workshops, see Ulrich Wengenroth, "Motoren für den Kleinbetrieb," in ed. Ulrich Wengenroth, *Prekäre Selbständigkeit. Zur Standortbestimmung von Handwerk, Hausindustrie und Kleingewerbe im Industrialisierungsprozess* (Stuttgart: Steiner, 1989), pp. 177–205.
3. Sigfrid von Weiher and Herbert Goetzeler, *Weg und Wirken der Siemens-Werke im Fortschritt der Elektrotechnik 1847–1972* (München, 1972), p. 46.
4. On the various types of drives for small-scale industry, see J. O. Knoke, *Die Kraftmaschinen des Kleingewerbes* (Berlin 1887). (2. verbesserte und vermehrte Auflage, Berlin 1899)
5. Several examples from the early 1890s can be found in the Krupp archives, Essen, WA VII f 799, "Maschinenantriebe auf der Gußstahlfabrik."
6. Wilhelm Stiel, *Textile Electrification. A Treatise on the Application of Electricity in Textile Factories* (London: Routledge, 1933), pp. 124–125.
7. See the Siemens archives, Munich, SAA 35/30 Ls 223.
8. Karl Meller, *Einzelantrieb von Werkzeugmaschinen. Ein Hilfsbuch für alle Metall verarbeitenden Betriebe* (Leipzig: Hirzel, 1927), p. 5. On cottage weavers, see E. R. Lembecke, "Versuche zur Erhaltung des Hausweberei-Betriebes im stadt- und Landbezirke Crefeld," in *Leipziger Monatschrift für Textil-Industrie*, Vol. 6, 1886, pp. 230–234; Vol. 7, 1886, pp. 280–281. For Switzerland, see Fritz Grieder, *Glanz und Niedergang der Baselbieter Heimposamenterei im 19. und 20. Jahrhundert* (Liestal: Kantonale Schul- und Büromaterialverwaltung, 1985), especially pp. 166–172.
9. See the documentation of the Berliner Gewerbeaufsicht for 1892, in Gerd Henninger, "Zu einigen Problemen der Elektrifizierung der Berliner Industriebetriebe von den Anfängen bis zum Beginn des 20. Jahrhunderts," in *Berliner Geschichte*, Vol. 2 (Berlin, 1981), pp. 46–51.
10. Georg Elten, "Einzelantrieb oder Gruppenantrieb?," *Maschinenbau—Betr.*, Vol. 12, No. 6, 1933, p. 164.
11. Texropes, or V-belts, which came from the United States, made their first appearance in Europe in Italy in 1929, where they were produced under license by the Soc. An. P. Alberzoni, Milano, which also supplied the German market. "Zeitschrift für die gesamte Textilindustrie," Vol. 32, No. 10, 1929, p. 175.
12. Allgemeine Elektrizitäts Gesellschaft, *Elektrischer Einzelantrieb in den Maschinenbauwerkstätten der A.E.G.* (Berlin: AEG, 1899), p. 85.
13. *Ibid.*, p. 65.
14. Otto Lasche, "Elektrischer Antrieb mittels Zahnradübertragung," *Z. Ver. Dtsch. Ing.*, Vol. 33, 1899, pp. 1417–1422, 1487–1493, 1528–1533, 1563–1569.
15. See, for example, the sales documentation in AEG archives document number X.179, "Elektrischer Einzelantrieb von Webstühlen, Verzeichnis der ausgeführten Einzelantriebe." Also *AEG-Ztg.*, January 1911, p. 99; also Stiel, *op. cit.*, p. 11.
16. W. Kübler, "Elektrische Einzelantriebe," *Z. Ver. Dtsch. Ing.*, Vol. 52, No. 22, 1908, p. 88.
17. Stiel, *op. cit.*, p. 108.

18. Stiel, op. cit., p. 109.
19. Stiel, op. cit., p. 112.
20. For a more detailed discussion of early electric drives in the textile industry, see Ulrich Wengenroth, "L'électrification dans l'industrie textile," (forthcoming in a collection of articles to be edited by the Association pour l'histoire d'électricité, Paris, 1992).
21. J. Irtenkauf, "Die Drehzahlnormung. Anwendung und Auswirkung bei spanabhebenden Werkzeugmaschinen," *Maschinenbau-Betr.*, Vol. 12, No. 2, 1933, pp. 39–43.
22. P. Möller, "Die Weltausstellung in Lüttich 1905," *Z. Ver. Dtsch. Ing.*, Vol. 49, No. 36, 1905, p. 1457; also Henry Behrens, "Werkzeugmaschinen," *Maschinenbau-Betr.*, Vol. 8, No. 11, 1929, p. 348.
23. On the many shortcomings of early gearboxes during the first two decades of the twentieth century, see Friedrich Schwerd, *Spanenden Werkzeugmaschinen* (Berlin, 1956), p. 171; and "Elektromotorischer Einzelantrieb an Werkzeugmaschinen," *Loewe Not.*, Vol. 6, October–November 1921, p. 83.
24. Notably trams, for example, but also cranes and conveyer belts.
25. H. Hoffmann, "Maschinenwirtschaft in Hüttenwerken," *Z. Ver. Dtsch. Ing.*, Vol. 56, 1912, p. 508.
26. Early examples of up to 25,000 kW can be found in *ibid.*, pp. 511–514.
27. Ulrich Wengenroth, "Die Elektrifizierung der Antriebe im Stahlwerk. Kräne und Walzwerksantriebe bis zum Ersten Weltkrieg," in ed. Horst A. Wessel *Elektrotechnik—Signale, Aufbruch, Perspektiven* (Berlin: VDE-Verlag, 1988), pp. 77–83.
28. Allgemeine Elektrizitäts Gesellschaft, *Elektrizität im Eisenhüttenwerk* (Berlin: AEG, 1922), p. 141.
29. H. Bonte, "Einfluß der Großgasmaschine auf die Entwicklung der Hüttenwerke," *Z. Ver. Dtsch. Ing.*, Vol. 52, 1908, p. 1914.
30. AEG, *Elektrizität im Eisenhüttenwerk*, op. cit., p. 142.
31. See "Drehstrom-Kommutatormotoren in der Papier- und Textilindustrie," AEG archives, document number G 4/1083, September 1932.
32. "Elektrischer Antrieb von Ringspinnmaschinen," AEG archives, document number G 4/2008, p. 3.
33. Stiel, op. cit., p. 208.
34. *Ibid.*
35. *Ibid.*
36. "Schablonen-Spinnregler," AEG archives, document number J 4/T 34a; see also Stiel, op. cit., pp. 251–256.
37. See "Drehstromnebenschluß-Spinnkommutatormotoren—Ausgeführte Anlagen," AEG archives, document number J 4/T 11.
38. Meller, op. cit., pp. 102–103.