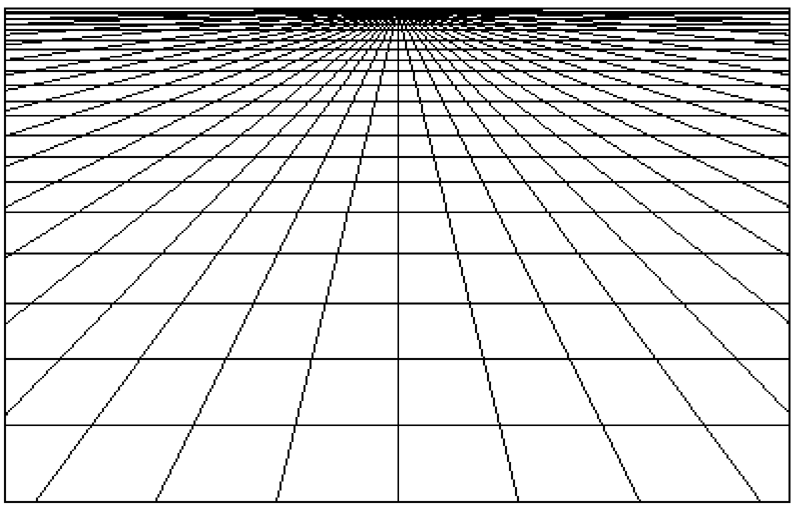

‘Steamy Encounters’: Bodies & Minds between Explosions & Automation in Early Cybernetics

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"For if every instrument could accomplish its own work, obeying or anticipating the will of others, like the statues of Daedalus, or the tripods of Hephaestus, which, says the poet, 'of their own accord entered the assembly of the Gods'; if, in like manner, the shuttle would weave and the plectrum touch the lyre without a hand to guide them, chief workmen would not want servants, nor masters slaves."

Aristotle, 'On reason, the state, slavery and women', Politics.

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In the memory of my grandfather.

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Special thanks are due to my friends and colleagues in the broader historical and STS studies respectively, Luminita Gatejel and Nicholas Sakellariou, and to my engineer friends Manos Manousakis and George Psimoulis for their insightful comments on discussing some of my ideas for this thesis and for their loving support. Last, but not least I thank the reader of this thesis for the apposite remarks. Of course, all mistakes remain my own.

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Synopsis

The history of minds, self-regulatory, feedback, automatic mechanisms has been unrelated to a history of bodies killed or mutilated by steam engine explosions during the long nineteenth century. In this thesis the rhetoric of automation, i.e. technical regulation, which has been indispensable for the gradual social predominance of engineering labor is contrasted to a synchronic historical reality of control disasters. This is further associated to the dissociation of minds and bodies in the capitalist division of labor, of heads from hands, with the first being presented as more important than the second in social terms. Finally, while feedback has been related to a liberal market-type self-regulation, the historical consideration of state interventions for the prevention of explosions related to feedback mechanisms points to the parallel development of the capitalist state as indispensable for the capitalist market.

Keywords: history of feedback, self-regulation, steam engine governor, explosions, rhetoric

1. Introduction: Unreconciled Aspects in the History of Automation[1]

The long 19th century, a century defined by the drive for automation, begins with crucial modifications of the steam engine by James Watt. What characterized above all this era's most praised machine was its governor (*cybernetes*), a feedback arrangement that was supposed to self-regulate the flow of steam between the boiler and the condenser, in order to maintain dynamic equilibrium. Feedback mechanisms, which stand out as the *par excellence* techniques of intelligent self control, have inspired the emergence of cybernetics, the discipline that contributed the most to the emergence of the cyberspace. An anthropomorphic perception of the governor as the mind inside the machine stands not only for a contemporary deterministic view of technology by and large, but it is also closely related to a black box ideology which has been underlying the dominant view of technology.

I started by studying the available literature on feedback mechanisms (whether mechanical, electric or electronic), from Otto Mayr's seminal works on mechanical feedback to David Mindell's pioneering studies on electronic

[1] This thesis is also a part of my PhD dissertation research project conducted at the Interuniversity Program of the History and Philosophy of Science and Technology (National University of Athens and National Technical University of Athens). The first half part of this introduction was based on a presentation paper at the Minds, Bodies, Machines Conference, entitled 'Automation's Darkest Hour: Mechanical Minds, Steam Engine Explosions, Mutilated Bodies' co-written with Aristotle Tympas and presented by myself on June 2007 at Birkbeck University.

feedback. As I read it, this literature hasn't differentiated as sharply as needed between the rhetoric of automation and a reality that was marked by limits to automation. Noticeably, Mayr started from the self regulation of the steam engine by the governor in order to argue that it was part and parcel of a self regulated liberal society, operating under the auspices of the institution of the market, which dynamically adjusts demand and supply.

A great number of steam boiler explosions have been haunting steam engines of all kinds, from Victorian Britain to Antebellum America. Occasions of bursting boilers were more than often lethal, turning human bodies into scorched flesh (and characteristically were a scoop for reporters). Thus, despite the presence of governors as, supposedly, artificial minds, steam engine explosions kept injuring or even killing human bodies. For the most part of the long nineteenth century, explosions were a fright for the masses and an itch for state authorities and the relevant civilian manufacturers and proprietors, whose interests were at stake.

Typical, were attempts to deal with the problem carried out by committees set up so as to shed light into the causes of steam boiler explosions, along with a quest for a proper safety legislation that was sought for at both sides of the Atlantic. Furthermore, based on a symptomal reading of the texts produced by these committees, I argue that there was an ever emerging need for skilled technicians and a broader understanding and control over the machine. This was not a period of a technical imperative prevailing spontaneously. It was through the laborious work of committees of this kind that the profession of the engineer was constituted and embedded with its accompanying technical authority and expertise. The reconfiguration of power relations that took place in the shift to a paradigm state rearranged the relations between minds, bodies and machines, by elevating intellectual labor (computing) as what mattered, while downplaying manual labor.

A history of minds, in this case machine minds, minds mechanical. Such par excellence mind has been the governor of the steam engine, the most paradigmatic machine ever. The governor was adapted to the steam engine in the late eighteenth century, at a period that coincides, not in my opinion accidentally, with the commencement of the long nineteenth century, the commencement of the industrial version of historical capitalism. The way the steam engine governor is described in words or portrayed in rough or exact sketches or photos has never been neutral, for there has never been such a thing as a technically objective way to write/speak about a machine or to draw a sketch of it.[2] Top engineering designers, themselves minds in the corporate division of labor were calling the governor a self regulatory mechanism and an equalizer of motion. At the bottom of a pyramidal hierarchy, where humans were supposed to be only bodies, the same mechanisms were nothing more than philosophical toys. Their intelligence was all but given for the low paid salaried technicians populating this bottom.

The history of the steam engine governor, as it can be reconstructed by the available historiography of technology is written from the perspective of the

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[2] See Steven Lubar, *Representation and Power*.

designing engineer, the perspective of invention. According to this history, the steam engine governor could intelligently adjust the internal operation of the steam engine to changing external circumstances. Based on the claims of its designers, this history has reproduced the assumption that the governor was an exemplar of machine intelligence because it has excluded from consideration how the governor was actually used.

Had the governor worked according to this assumption, no steam engine explosions would have ever been possible, because the governor would have prevented them. But explosions there were. As a reconstruction of some work by social, intellectual, cultural, labor, and institutional historians suggests, these explosions were the rule, not the exception since the beginning and over the course of the long nineteenth century. Staying at the technically abstract, historians of the steam engine governor have not told us why its use failed to prevent steam engine explosions. On the other hand, historians of steam engine explosions have also detached the social and the technical, by failing to consider why the steam engine governors used failed to prevent the accidents or why a steam engine governor may not have been used to start with. In the first case, we have a history of machines enlivened by mechanical minds that held no relation to dead bodies. In the second of dead bodies, unrelated to minds. In this thesis I attempt to bring minds, bodies, and machines together, by pointing to a history that is focused on how mechanical bodies and social bodies were related.

The available historiography on steam engine governors focuses at the market and neglects the state. It does so because the state has no parallel in the idealized operation of the steam engine governor, which provides a market type self regulation. By contrast, the available historiography of steam engine explosions is focused on the state, which is portrayed as the institution that limited the explosions by providing external regulation. This co-consideration of steam engine governors and steam engine explosions suggests that the market and the state were co-developed, with the capitalist state being an indispensable institution for the capitalist market and vice versa.

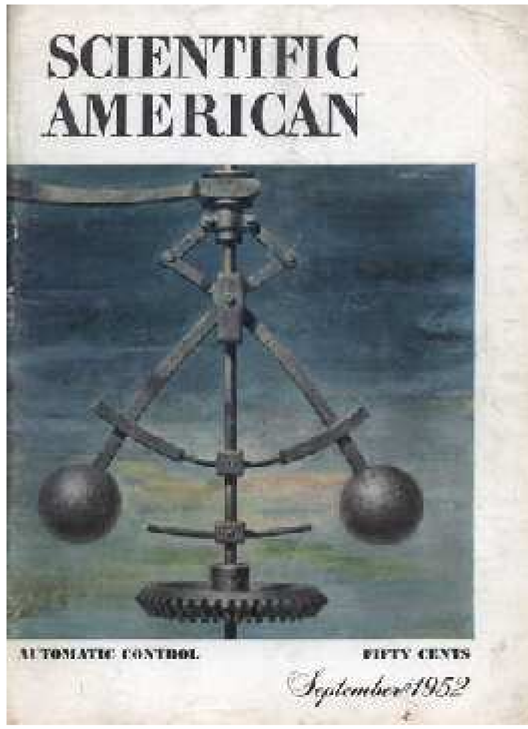
Furthermore, I attempt in the conclusive chapter a philosophical revaluation of the case study, by drawing some correspondence lines between overaccumulation crises in historical capitalism and overpressure (boiler) and overspeed (flywheel) explosions, which I treated in the Fourth Chapter. What seems interesting is that the engineering reasoning of the working of the steam engine, and the overview of it as a machine composed by a tank (supply) and a motor (demand) two compartments that have to be maintained in an equilibrium, has some considerable analogies with the classic and neoclassic economic reasoning of the equilibrium between supply and demand in a self-regulated market. The cases of steam engine explosions and of economic crises in capitalism refute the laissez-faire ideology, by pointing to the state as the institution whose apparatuses play an overall reproductive and compensative role both in cases of technological disasters and of economical ones that have clear social consequences.

Last I have attempted to challenge the view of technology as an autonomous force, as a 'neutral' tool and a black box as well, and I close the thesis by making some remarks over the ideology of automation, that is of technical self-regulation. According to my reading technical self-regulation corresponds to the conception of the individual as possessor or himself and of a free will, the juridical or liberal subject of the Enlightment. This further raises some questions in regards to the human-machine relationship.

My work has been theoretically inspired by the French Continental philosophical tradition, and in particular by the works of Louis Althusser and Michel Foucault. I chose to move along the STS path and follow David Bloor's suggestion for symmetry in the consideration of "true and false" beliefs, by thinking rather inexplicitly under the foucauldian category of 'forms of rationalization'. I have employed Althusserian symptomal reading in order to study the archival material, which means that methodologically I have tried to look into how mechanical self-regulation was conceived not by contemporary standards but in the context of my human historical actors' own terms and concepts, taking into account all their contradictions and silences.

From what I present here I hope that it will become clear that methodologically I do follow the symmetrical imperative for the treatment of human and non-human actors following in these Bruno Latour, John Law, Michel Callon and others. Indeed artifacts and technologies in general actively shape our social and virtual worlds, but they are always caught up in historically specific power relations, if not power play. In this way and by way of retrieving distinct views over technologies through the development of the issue I also cared to prevent Susan Leigh Star's allergic reactions.

2. From Cybernetes to the Cyberspace: Feedback as a guiding thread in the history of automatic control



Watt's steam engine governor posing on the cover of the September 1952 issue of the *Scientific American*, dedicated to automatic control.

(http://blog.modernmechanix.com/2006/03/30/automatic-control/)

Feedback mechanisms stand out as the *par excellence* techniques of intelligent, automatic self control. Control is exercised by negative feedback, thus feedback mechanisms. This genre of self regulatory, automatic control mechanisms inspired after WWII, the emergence and formation of Cybernetics, a discipline that made contributions to the making of the cyberspace, as well as to several of the disciplines that participate in the scientific frontiers of our days (e.g. IT, AI, cognitive psychology, game theory, OR).

Cybernetics was an interdisciplinary field organized by mathematicians, who tried to couple communication and control, and bring under the same theoretical umbrella phenomena as divergent as physical, mental, technical, and psychological. In so doing cyberneticians favored an all-inclusive understanding towards nature and society, towards the natural and the artificial, and thus towards humans, animals and machines. And we may notice the correspondences with actants, machines as active agents, in actor-network theory. The cybernetic premise has been reproduced widely in divergent intellectual domains including humanities and literature (especially science fiction literature starting with Isaac Asimov and Philip Dick) to the fine arts along the twentieth century till the present day. According to this premise the common denominator between these entities is the principle of (negative) feedback. Shifting the formation of conceptions of par excellence feedback processes from homeostasis to reflexivity and more recently to virtuality, through its abstraction the cybernetic premise has since been displacing emphasis from materiality to immateriality. [3]

The Periodization 'Early Cybernetics' which figures in the title of this thesis might and actually should appear misleading to the cautious reader. It is anachronistic since there had been no conception of the abstract schema, the 'principle' of the feedback loop until it was coined up by the father of Cybernetics,

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[3] See Katherine Hayles, How we became Posthuman, The University of Chicago press, 1999 and for the relation between art and cybernetics see Claus Pias, *Zombies of the Revolution*, at www.uni-essen.de/~bj0063/texte/banff.pdf.

Norbert Wiener. Far from any essentialism it is used to illustrate the retrospective effectivity of naming and the inter-subjective, i.e. social, production and reproduction of meaning.

The ground work for the history of feedback mechanisms has been laid out by a major historian of technology, a German mechanical engineer, who became chairman of the dept. of History of Science and Technology, Acting Director of the National Museum of History and Technology and curator at the Smithsonian Institution during the early 1970s, Otto Mayr. During this time, Mayr took up the task to tie into one historical thread this disseminated genre of mechanisms, whose earliest manifestations went deep into antiquity. His work sufficiently covers the ‘genealogy’ of the mechanical versions of feedback mechanisms from antiquity to the late nineteenth century. After him histories of their electrical and electronic versions have followed, although divergent historiographically. On their whole, by underlining the technically abstract these narratives have neglected to consider how negative feedback mechanisms were used, and ultimately escaped taking into account cases of accidents and malfunction, although there are references to be traced there.

Since the late eighteenth century several ‘self acting’ mechanisms, that maybe considered as belonging to the category of feedback mechanisms, had been devised, among which the safety valve controlling pressure in the boiler, the float valve controlling water in the boiler, many versions of mechanisms controlling velocity and the output of power like the cataract and the float regulator, all of which were able to achieve static equilibrium. According to the canonical history of feedback mechanisms, the governor was the first mechanism embedded to achieve a dynamic equilibrium between the boiler (the generator) and the moving parts of the engine (the motor), and thus maintain a uniformity of the engine's motion and a steady state operation.

Otto Mayr's book, Feedback Mechanisms, brings under the category of feedback a wide variety of mechanical feedback mechanisms that appeared since the late eighteenth century, emphasizing along continuity. The mechanisms presented and described are exhibits of the (American) National Museum of History and Technology, and most of them are different types of governors. He has used three generally accepted criteria of his time in order to define and trace feedback mechanisms. It was under the hegemony of the general conception of feedback that a wide variety of mechanisms could be brought under the 'feedback' label, while they expose several differences that make their sub-classifications particularly complex.[4]

The first definition is based on the property ascribed to the mechanism and is given by Norbert Wiener, "the property of being able to adjust conduct by past performance", and the second one is based on the form of functioning given by the American Institute of Electrical Engineers in 1951: "A Feedback Control System is a control system which tends to maintain a prescribed relationship of one system variable to another by comparing functions of these variables and using the difference as a means of control". Additionally Mayr incorporates a third

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[4] See, Bernstein, Dennis S., *Feedback Control: An Invisible Thread in the History of technology*, IEEE Control Systems Magazine, April 2002, pp. 53-68.

criterion. This last criterion has two aspects, one mathematical according to which every self regulating system can be said to be a closed loop with negative feedback, if it displays a certain stability under the influence of external disturbances, but which should also ‘incorporate a *physically* distinct element with only the function of seeing the output, that is generating a feedback signal’ (my emphasis).[5]

The first definition leaves the procedure of adjustment as a black box, thus making feedback an all-inclusive schema, and it is in this way that it obtains a universal status. According to this definition a feedback mechanism is supposed to anticipate the future by adjusting to past conditions. It thus *produces* the future by means of the prefixed relation between the system and the mechanism attained when they are coupled in a negative-feedback manner. Of course this procedure has several shortcomings, which have been acknowledged mathematically. The second one is an algorithm that requires *computing* a difference between values in order to maintain a prescribed relationship whose effect is *regulation* (or control). The third definition ascribes the function indicated in the second definition to a *physically distinct element* –furnishing the black box. The block diagram below is an example of the way feedback is represented in engineering and scientific textbooks.

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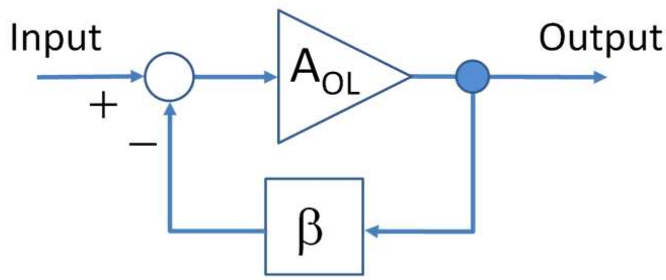
[5] Mayr, 1971, pp.1.



Both Mayr and Bennett’s historical accounts of feedback and control mechanisms of the first industrial era (mechanical) have underlined the importance of regulation in the history of feedback mechanisms. And as the mathematical formulation of a theory of dynamical systems of control, laid the ground for the conception of feedback, they have studied the history of the formation of this mathematical theory which was found to be related to problems of regulation. Their mathematical treatment was brought forth by industrial experience in regulation but was completed only in the first decades of the twentieth century with the development of the next generation of mechanical feedback mechanisms, servomechanisms.

The governor beyond the industrial settings was also used as a velocity regulator embedded on telescopes to make them rotate uniformly. The British astronomer G. B. Airy made a first attempt in 1840 to study it mathematically but he left it unfinished. The first mathematical treatment of the functioning of governors with the use of differential equations was provided by Maxwell, who solved it up to a third degree differential equation. Following his friend C. W. Siemens who had devised a rather ‘eccentric’ kind of governor which acted isochronously, he distinguished between *moderators* and *governors*, as a difference in presenting or not offset. Maxwell's paper is said to have remained, however, unread until the early twentieth century.

Otto Mayr has followed the work of six physicists of the Victorian era involved with speed regulators G. B. Airy, C. W. Siemens, J. C. Maxwell, Lord Kelvin, L. Foucault and J.W. Gibbs. It is interesting to note as Bennett and Mayr inform us that except from the last two, these men were personally acquainted. Their endeavors either were motivated by research in scientific instrumentation or by 'the hope for economic gain from a successful invention'. However their work remained totally ignored by industry. As Mayr has taught us, successful governors in the industry, such as C. T. Porter's loaded governor, were not products of science but of practical ingenuity, that combined simplicity with economy and efficiency. Characteristically, Porter's loaded governor was not the product of complex differential computations, but a product of practical intuition that was later studied by means of geometrical representations. The indicator's diagrams provided by the improved Richard's indicator were of the outmost importance in adjusting both the governor and the cut-off point of the differential gear mechanism set up by Allen to work as a filter when connected to the governor.[6] Scientific and engineering endeavors though using the same mathematical languages posed different problems, and had diverging scopes and aims.

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[6] See Otto Mayr, *Victorian Physicists and Speed regulation*, 221-222. See Otto Mayr, *Maxwell and the Origins of Cybernetics*, Otto Mayr, *Yankee Practice and Engineering Theory* and also Stuart Bennett's <u>The History of Control Engineering 1800-1930</u>.

In an internal historical style, as given to us by Bennett and Mayr, Watt's fly-ball governor is considered the most characteristic of proportional action, and it was suitable for low pressure and low speed engines, which remained the majority in use till the end of the nineteenth century for economical reasons, even if their fuel consumption was higher than in the case of high pressure engines. Along with the claim for more power came Oliver Evans and Robert Trevithick's reciprocating high pressure engines patented respectively in the United States and in Britain. These high pressure engines proved to be a lot more prone to boiler explosions. In their initial designs, none of them bore a governor. Louis Hunter, speaking of the hazards of high pressure steam, writes: "[T]he development of the steam boiler and its equipment was governed almost entirely by quite practical considerations of what was suited to American conditions, what would work, and how much it would cost. One factor above all others was controlling: the early acceptance and general adoption of the principle of high pressure steam and non condensing practice. The advantages of the simple, compact, low cost high pressure steam engine over the low pressure engine with its complicated condensing apparatus, greater size and weight, and heavy requirements of condensing water were clearly manifest and so appropriate to American conditions – scarcity of capital and skilled labor, scarcity of repair facilities and limited scale of operations – that a wide consensus was early reached, with virtually no debating of the issue, save in respect to steam navigation." [Hunter, 1985: 353]

As historians of technology have told us, the endeavors of most of the ambitious practical men were turned to the governor, as the one that would –finally- prove the best equalizer, while most of the other self acting mechanisms remained more or less unchanged. Nearly one thousand patents of governors were reported at the US Patent Office during the first half of the nineteenth century. [7] Quite a success in employing 'proportional plus derivative control' were the shaft governors that came to use after the 1860s, because of their suitability for high speed engines. They were usually located within the flywheel, another velocity –energy storage but not feedback- regulating device which used its huge mass as inertia to maintain a steady motion.[8] Shaft governors came to be used extensively on boats because of their lack of dependence on gravity, which rendered the centrifugal governor unsuitable for such usage. The absence of governing on steam boats before the adoption of shaft governing indicates the limitations in a general application of the Watt governor.

What is considered to be the successful closure of a long quest for a uniform and equable motion, just before the threshold of the electrical era, came

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[7] For an earlier account of the patents by engine-builders see, Bennett, 1975 and for the outburst in the patenting of governors in US and only for the first half of the 19th century see Bennett, 1979.

[8] "Flywheel and governor were devices with closely related functions. In their different ways each served to regulate, that is, make uniform, the rotating motion of the engine and of the machinery driven by it under varying conditions of work load and power delivery. […] In the regulation of engine speed, the relation between governor and flywheel is most complicated." [Hunter, 1985: 121-2].

with the Porter-Allen high speed engine which incorporated three decisive elements: Porter's loaded governor, Richard's pressure indicator and Allen's automatic cut-off gear.[9] Following the same pattern of marrying efficiency with economy, while excluding close regulation, however economical and efficient those high speed automatic cut-off engines were for large scale production in the turn of the twentieth century the majority of engines used were still of the fixed cut-off and throttling type:

'The most striking fact […] is that at the peak of the reciprocating engine's triumphal progress through the Western world, three-fourths of the stationary engines built and bought in the United States in 1899 were of the old-style fixed-cutoff, throttle-governing mill engine of the antebellum years. […] Cheap fuel and high prices of materials and labor, declared Thurston […], often 'made the uneconomical [engine] best'." [Hunter, 1985: 507]

In summarizing the historical evolvement of control engineering Stuart Bennett writes:

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[9] 'Watt and Southern quickly realized that the indicator diagram could be used to give a direct measure of an engine's power' Hills, R.L. and Pacey A.J., 1972: 40. 'The indicator diagram must have been extremely valuable in adjusting the valves of a new engine', 42. Tuning of an engine by using the characteristic curve is still the single most important thing for an engine to function properly.

'[T]he way forward towards a clear understanding and a mathematical formulation of the theory of feedback systems was through engineering: first through mechanics – the regulation of prime movers led to an understanding of stability, the positioning of heavy loads to the development of servomechanisms – and then, as difficulties of analysis of mechanical systems began to hinder further progress, through electronics, and, in particular, through the need to obtain low distortion in the amplification and transmission of telephone signals. This phase occupied 150 years, a period extending roughly from 1790 to 1940 […] It was during the World War II, with the need for servomechanisms to operate at higher speeds and with much greater precision than previously thought possible, that engineers and mathematicians came together to create the control engineer' [Bennett, 1979: 3].

David Mindell has given us a material history of the electronic version of feedback (see the diagram of an electronic feedback amplifier below) and control before cybernetics, in his book Between Human and Machine for the period 1916-1945. As he explains, 'Despite my interest in machinery, this is not what historians call an internal account –a genealogy of hardware and ideas, separate from the world. Such histories tend to impose a logic and coherence to events that they lacked at the time.'[10] Mindell's historiographical method employs the cybernetic premise on an epistemological basis of his book, but as he argues this

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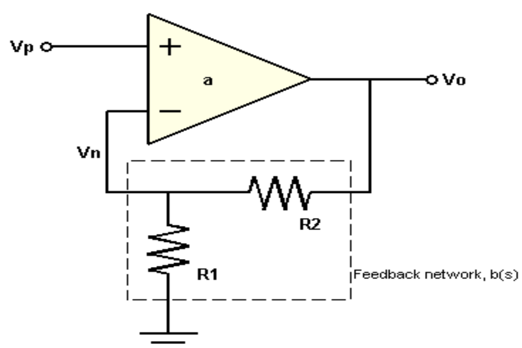
[10] David A. Mindell. Between Human and Machine: Feedback, Control, and Computing before Cybernetics. (Johns Hopkins Studies in the History of Technology.) Baltimore: Johns Hopkins University Press. 2002, pp.12.

is also in a conceptual agreement with the systems' sciences of the period he studies. His human-machine approach appears to be a 'conscious' employment of the cybernetic epistemology, which in his historical case study falls more than close with his historical actors' somewhat 'conscious' somewhat 'unconscious' dealing with control systems.[11] Agreeing with B. D. Geoghegan we may underline his observation that, "These material histories corroborate an old cybernetic premise; that machines are active agents in their world, whose behavior provides insight into the structures, constraints, and laws of human society […] Writing amidst a proliferation of global information systems and human-computer couplings in Western white-collar life, material historians not only remember the information machines but also *embody a revival of cybernetic epistemologies*".[12]



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[11] 'Perception, articulation, and integration form a historical schema to organize the history of control systems; all who built control systems worked with these elements in some form, though not usually with this nomenclature.' Mindell, 2002, pp. 23.

[12] Geoghegan, Bernard Dionysius, "The Historiographic Conceptualization of Information: A Critical Survey", IEEE Annals of the History of Computing, January-March, 2008, pp.75.

Feedback in its abstract form has also served as an anachronistic demarcation line between a technological culture preeminently occupied with the construction of automata and a following one that starts with industrialization and where feedback mechanisms appear to be in increasing numbers embedded on machines from the mechanical to the electrical and to the electronic. Clock-work automata had a top-down function, one that was solely determined by the initial conditions of their making. In contemporary terms they are called sequential mechanisms, and unlike feedback's representation in cyclical diagrams, theirs are linear. Adversely, feedback mechanisms despite of the determinacy of their construction (their geometry and proportions that have to be computed), they didn't perform as a ready reckoner but were supposed to dynamically adjust to changes of the external conditions.

Mayr's engagement in the historical study of feedback mechanisms sets out from scratch in support of the main argument that made his work famous, and which obtained its most elaborated status in Authority, Liberty & Automatic machinery in Early Modern Europe, published in 1986. By studying feedback both in the technical and the economical literature of this time, Mayr contemplates a parallelism between two opposing pairs, one denoting a passage in the hegemonic conceptions of order, and another epochal shift in the material manifestation of a technical imperative as yet *inexplicit*: liberalism-authoritarianism and feedback control-automata.[13]

In his 1971 paper *Adam Smith and the Concept of the Feedback System, Economic Thought and Technology in 18th century Britain* Mayr observes that Adam Smith's economic theory of supply and demand takes the laissez-faire scheme of the physiocrats one step beyond, thus being the first clearly articulated feedback scheme in the liberal political tradition. The article attempts to find possible contacts between Adam Smith and this genre of mechanisms in order to concretely support his argument of their co-emergence with some kind of causality. Nevertheless, what he does find is some close ties of friendship connecting Adam Smith with James Watt and some other influencing engineers of the time, which suggested at least that Adam Smith had most probably seen the centrifugal governor in action. Failing to wholly break away from the shadows of the Hegelian Zeitgeist he was forced to stay within spatial and temporal contiguity instead of causality. [14]

Since the history of feedback mechanisms goes way back to the ages of Hero and Ktesibios of Alexandria, Otto Mayr intelligently questions in Authority, Liberty & Automatic machinery in Early Modern Europe their absence from

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[13] See also, Bennett, Stuart, "Otto Mayr: Contributions to the History of Feedback Control", IEEE Control Systems Magazine, April 2002, pp. 29-33.

[14] See Conclusion in Mayr, Otto, "Adam Smith and the Concept of the Feedback System, Economic Thought and Technology in 18th century Britain", Technology & Culture, vol.12, n.11, pp. 1-22, January 1971.

literature and the intellectual imagery in mid-eighteenth century Europe. Hence, he links the dominant political, social and economical ideas of these historical periods with the prevailing of specific technological artifacts. Europe's authoritarian constitutions, the emergence of the scientific revolution with its mechanistic world-view and the mechanistic philosophies of the 16th and 17th centuries are linked to the preference of clockwork mechanisms in clocks as well as in automata, whose function depended wholly upon the initial conditions of their construction. Clocks had a centralistic and fully deterministic command structure as the flux of information was single-downward, analogous to the mode of governance in Europe that period. Following Mayr's argument, the governor's initiation and expanded use had to wait until the configuration of forces leaned in favor of a more liberal conception of order, which in the first instance appeared during the 18th century in Britain.

It is interesting to note that some twenty years earlier, in 1947 Norbert Wiener, had himself divided 'the thoughts of the ages' into three epochs, by linking the technical with the economical: the age of the science of clockmakers, surveyors and planetary astronomers used in naval navigation and characterized by the mercantilist economy, followed by the age of the steam engine characterized by the manufacturers instead of the traders economy, and finally his own age, the age of information and control.[15]

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[15] For this note see Galison, Peter, "The Ontology of the Enemy: Norbert Wiener and the Cybernetic Vision", Critical Inquiry, Vol. 21, No. 1 (Autumn 1994), pp. 252.

Stuart Bennett's The History of Control Engineering 1800-1930, the first of two volumes taking the history of control systems up to 1955, also begins by presenting a suggestive genealogy of the concept of feedback: in the economic theory from Adam Smith to Keynes, from the natural theory of Darwin to the regulatory function of 'homeostasis' coined up in the nineteenth century. Philosophers from the classical thought up to Hobbes and Leibniz favored a geometrical reasoning in explaining the way political society is balanced. Machiavelli on the other hand marks a shift to a dynamic conception of the balancing of society. The prince's art of government consisted in taking into account the state of affairs, and his virtuosity was grounded in maintaining control of things and people whose course might be diverged by aleatory factors (fortuna).

Bennett draws an internal distinction as to the concept of feedback between a static and a dynamic mode of achieving equilibrium. This is according to Bennett the distinction between geometrical (static) and analytical (dynamic) mode of reasoning. As we may read from a history of science literature the primacy of geometric reasoning was gradually overset by the wide expansion of industrialization and the diffusion of the factory system into society. The usage of the differential calculus that is in accordance with an analytical mode of reasoning, as against a graphical mode of calculating linked to geometry, was needed for the understanding of dynamic equilibrium, that began being extensively used and conceived in mathematical terms from the dawning of industrialization onwards.[16]

For example, while the limits of the governor to intervene and maintain a dynamic equilibrium have been accounted from the history that treated the several arrangements and their mathematical understanding, and while in passing Mayr and Bennett do relate the governor with accidents, the question of the relation between these mechanisms and the steam engines that kept exploding and killing people all along the nineteenth century has been escaped. Technologies in their in-use state, involve no artificial purity. Like the wittgensteinian ladder, the impure state is perpetually thrown away mutating discourses and freezing technologies into black boxes. Historians of feedback and control engineering have given us histories of feedback and control that have opened up the black box in internalist and/or biased ways. What we actually lack is an historical account of feedback mechanisms that will bring the technical and the social together. Focusing only on the labors of the top of the pyramidal division of labor, produces histories of engineering problem solving from the point of view of the top engineering designers and constructors, minds themselves in the corporate division of labor that have not sufficiently cut ties with their actors' rhetoric.

The steam engine governor (a mechanical regulator), the artificial line (an electrical regulator), and the electronic negative amplifier (an electronic regulator)

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[16] See W J Ashworth, *Memory, efficiency, and symbolic analysis: Charles Babbage, John Herschel, and the industrial mind*, Isis **87** (4) (1996), 629-653.

taken together, as Aristotle Tympas has shown in studying the artificial line, stand "at the center of the drive for automation, i.e., technical regulation (network self regulation), that marks historical capitalism, from the radical change in the pattern of production of space introduced by the cybernetes (governor) of the steam engine to the expansive reproduction of this pattern that brings us to the cyberspace."[17] More recently Tympas has also noted the importance for computation in the construction and adjustment of steam engines of the slide rule as an early computing artifact, thus questioning the canonical Periodization of the history of computing starting in the second half of the twentieth century.[18]

'Feeding back' feedback conceptually and epistemologically has 'superimposed' (another 'feedback' concept of electrical engineering) the perpetual struggle between computation and regulation that was at the centre of the endeavors from the perspective of the engineers. Emphasizing feedback and holding to the rhetoric of automatic control has also cost us to overlook the degradation of manual labor, which was downplayed in relation to computation, with the later achieving a status of being what *really* mattered in regulation. "What we find in this analysis is typical of the ideology that presents negative

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[17] For this and for the use of the couple computation-regulation as an analytical conceptual tool for the historical study of feedback arrangements see Aristotle Tympas, "The Computor and the Analyst: Computing and Power 1870s-1960s", PhD dissertation, Georgia Tech, 2001.

[18] Aristotle Tympas, "*Did the computing revolution start after or in parallel to the industrial revolution? Presentations of computing in influential steam and electricity treatises*", forthcoming presentation at the SHOT 50th anniversary meeting in October 2008.

feedback network action as providing with technical regulation (automation), i.e., network self-regulation: along a self-referential mode of thinking, instability from an external cause is conceptualized as an impossible action because it is countered by internal circuit reaction. Just, however, as the concept 'dog' cannot by itself bark (Spinoza) the computation of 'automation' could not by itself automate. In the last instance, it was not computation that determined regulation but regulation that determined computation. In this case, as Evans admitted, regulation (stability) turned out to be something very different than what early analysts computed it to be. "[Tympas, 2001: 294]

Exactly because as Stuart Bennett argues in studying the six methods for equalizing motion proposed by James Watt in 1782, "There was no recognition of the difference between open loop and closed loop control, all devices were regulators. It was only after the introduction of the fly-ball governor, the device which *has come to epitomize the concept of feedback*, that this understanding began to emerge" (my emphasis), and as we have now seen from the above, feedback was coined a century and some years later, we should try to draw another demarcation line in the history of the steam engine governor, that will give us a picture of practices that were actually used and reproduced as a pattern from cybernetes to the cyberspace.[19] An example of how the governor was widely conceived within engineers may be illustrated by the following passage:

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[19] S. Bennett, "*The search for 'uniform and equable motion' A study of the early methods of control of the steam engine*", INT. J. CONTROL, 1975, vol. 21, No. 1, p.113-147.

"In addition to this mode of regulating the velocity of the steam engine, a variety of plans have been suggested for equalizing the admission of steam; the most simple of which is by means of a handle connected with the throttle-valve. This is a thin circular vane placed in the steam pipe, turning on a pivot across its centre, which comes through the pipe, and has a small handle fixed on the end of it, by turning which, the passage is opened or shut. […] so that by thus turning the handle, the attendant can at any time regulate the speed of the engine. The governor or double pendulum, is also employed for this purpose. This consists of two balls, suspended by joints projecting from a vertical axis, which being caused to revolve by the machine to which it is connected, will increase the diameter of the path described by the balls with increasing speed of the machine; or, in other words, their centrifugal force will cause them to fly off from the arbor in a degree proportionate to the velocity of the machine; and this motion is made to actuate the lever connected with the valve, which admits the steam from the boiler to the cylinder." [Partington, 1822: 132-135]

By providing both for a repeated but not homogeneous production of inter-technical practices, which played a constitutive part in the formation of the strata between the polarized classes of proprietors and workers as well as for the reproduction of the pattern of regulation by using negative feedback couplings, the perpetual struggle between computation and regulation within historical capitalism, exemplified by A. Tympas' work on the artificial line, may be considered as a way of writing the history of computing that has cut essentialist ties; an essentialism that has been repeatedly observed to cause a concealment of labor. It simultaneously provides with the means for a differential historical view when used synchronically of the *relative*, i.e. historically specific, divisions of labor within the technical strata from cybernetes to the cyberspace.

3. Steam Boiler Explosions and State Interventionism

A great number of steam boiler explosions have been haunting steam engines of all kinds, from Victorian Britain to Antebellum America. Whether it concerned steam boats, steam locomotives or stationary steam engines, explosions didn't seem to make any discrimination. Occasions of bursting boilers were more than often lethal, turning human bodies into scorched flesh and characteristically were a scoop for reporters. Thus, despite the presence of governors as, supposedly, artificial minds, steam boiler accidents kept injuring or even killing human bodies. For the most part of the long nineteenth century, explosions were a fright for the masses and an itch for state authorities and the relevant civilian manufacturers and proprietors whose interests were at stake.

Steam boiler explosions had taken a heavy toll of life and limb especially of those working near the engines during the nineteenth century in the United States, in Britain, as well as in Germany and France. A little will be discussed at the end of the section from the available literature for the French case, while the German case is not addressed here. Even if in Britain fatalities were more restricted numerically than in the United States, as all British engineers of the time acknowledged, they were a familiar concomitant of the age. Such explosions occasioned on an everyday basis at Manchester, but when there were no victims involved they were doomed to oblivion. The Scottish engineer and boiler expert of the early nineteenth century, Robert Armstrong, illustrated that explosions were not exceptional events of an otherwise safe and 'normal' working of the engines, but on the contrary they were part and parcel of steam powered production. Their avoidance was a matter of the labors invested in order to safeguard the whole process, the means of production and the bodies of labor.

"It may be asked, if our theory of steam boiler explosions be correct, how it is that we have not many more of them, as the causes to which they are ascribed may seem to be of everyday occurrence? The answer is, that the *bursting of boilers* is also a matter of everyday occurrence, to an amount which the public generally are altogether ignorant of. To be sure these burstings are not generally called *explosions*, although in reality they are so, being different only in degree. It would not be difficult to prove that two or three of these minor explosions occur in Manchester every week; but when no fatal consequences ensue, and no particular damage is done to any adjoining property, of course the circumstance never gets in the newspapers, and no public notice is taken of it." [Armstrong, 1839: 240-1] [20]

Explosions rained thick on every branch of manufactures and steam driven transportations and there is extensive archival material from treatises and journals written by expert mechanics of the time that were in search of the causes that provoked explosions both in the scientific manner of general inquiries and as to the cases at hand.

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[20] Most of the primary literature that has been used in this thesis has been selected from material provided to me by Aristotle Tympas' research at the Smithsonian Institution, others were gathered by my research at the British Library, and the rest are referred in the bibliography to sources I found through searching in the web.

"Sultana Painting by Marion Bradford Thompson, Jonesboro, Arkansas. On April 27, 1865, the steamship Sultana, while overloaded with mostly Union soldiers, exploded and sank in the dark of the night on the flooded Mississippi River near Memphis, Tennessee. More than 1,800 soldiers lost their lives in this horrific accident. Some of the soldiers aboard the Sultana were paroled prisoners who had survived the prisons of Andersonville and Cahaba only to perish in the fiery explosion and the cold and muddy waters of the Mississippi River. More lives were lost on the Sultana than were lost on the Titanic and the Sultana tragedy still stands as America's worst maritime disaster."

Taken from: http://freepages.history.rootsweb.com/~indiana42nd/Sultana.htm

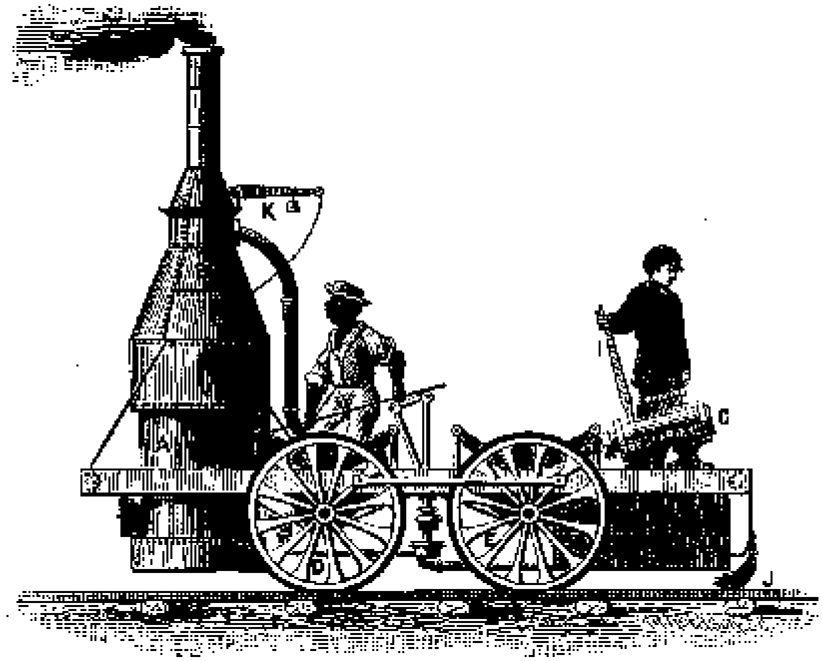
In the antebellum United States and only in steam navigation, during the period 1816-1848, 233 steam boats exploded leaving 2536 dead and 2097 injured, while loss in property went up to 3 million dollars.[21] In his article *Bursting boilers and federal power*, John Burke points out that the diffusion of the use of

[21] John Burke, *Bursting Boilers and the Federal Power*, pp. 18.

the steam engine played a major part for the consolidation of interventionist politics in the private domain driven by the claim for the safety of the public. According to Burke, the change in the point of view that the American Congress held was not instant, but was conduced gradually from 1816 to 1852, with a succession of delegations and legislative attempts. The belief that the proprietor's interest sufficed to ensure public safety was strongly held and for a generation or so, the congress remained reluctant to intervene in a decisive manner in the private domain.

From the initiation of high pressure engines onwards, the use of steam expanded dramatically. Even though there were specific guiding lines to the construction of boilers, for reasons of economy, low quality materials were chosen and quite frequently many of the mechanisms embedded on steam engines malfunctioned. For example in steam boats, water being drawn from rivers ate away boilers. The oddments in the boilers were not frequently cleaned, a job that was extremely painstaking as it required the worker to drag inside the dirty boiler in a repent manner. The fact that for reasons of economy in intermediate stops fuelling pumps were being held closed, while the fire wasn't put off, had also led to explosions. Safety valves were quite often held down in order to increase speed, which was the frequent practice for steam boats competitive races. Unqualified enginemen were hired and put into work without any proper training.

Federal government entrusted and financed an inquiry led by the Franklin Institute of the State of Pennsylvania. It was the first time that a government put a budget to a society for such a cause. Franklin Institute was established in 1824 and became a predecessor of the technical universities that were also established during the nineteenth century. Its founders were young men of science, who called themselves philosopher mechanics. This was the institute assigned with the task to investigate steam boat explosions. The history of the Franklin institute has been written by Bruce Sinclair, historian of technology, in his book Philadelphia's Philosopher Mechanics. Both from Sinclair's study and from the *General Report on the Explosion of Steam Boilers* the Institute compiled, we can see that the inquiries were developed by a series of experiments that attempted to reproduce conditions and check their relevance to explosions. These experiments were focused on finding the causes of explosions, but were also concerned with disproving several theories about explosions that were widely held. The pressure under which these experiments were carried out was large. Municipal authorities were the first that pushed for a thorough investigation of the causes and especially with the diffusion in the use of high pressure engines.



This is a sketch of the *Best Friend* locomotive (1830), taken from A history of the growth of Steam Engine, by Robert Thurston, 1878 (http://www.history.rochester.edu/steam/thurston/1878/). Aldrich refers to its explosion that took place in June 1831 and which took the life of the black fire-man depicted. As Aldrich notes he was a slave and his name has been forgotten. [Aldrich, 1997: 10-11].

The General Report of the Committee of the Franklin Institute provided a thorough account of the causes of explosions, while at the same time including an account of assumptions that where tested and found to be irrelevant in provoking explosions. A. D. Bache who was in chief of the experiments was quite insistent in this, because several assumptions concerning the causes of explosions had been put forward that were completely unscientific and thus invalid, and equally stimulating for the public imagery. In example the most provocative of these theories held that boiling water dissolved into hydrogen gas in the boiler and was responsible for the explosions. As we can imagine if such an assumption held, it would also mean the very unsuitability in using steam as a medium.

The Report included also an analysis of the working of several safety devices and to the contemporary developments in their design, an account of the materials used for the construction of boilers along with some guiding lines for their maintenance and for the inspection of the processes performed by the steam engine. This series of experiments had definitely assumed the status of an exemplary engineering research for the engineering community whose institutional formation outside industries was being set up during this period. Experimental results were shaped into three suggestive categories of regulation and were represented in the form of a legislative Act. First, the formation of an inquiring system was proposed along with a system for the certification of boilers. Second, specific prescriptions for the construction of safety devices, procedural functions and qualifications of personnel were given and third, penalties in cases of misbehavior and improper operation were put forward. According to Sinclair, the rhetoric of the text compiled by A. D. Bache had ‘everything needed in order to be easily digested by the Congress’.

In 1836 the American Congress decided to appoint a committee for the investigation of explosions, but it was only in July 1838, a year stroke by a great number of explosions that an Act was voted. It highly rested upon the suggestions of the General Report of the Franklin Institute, although several modifications were made and much less details were maintained than the proposed legislative act composed by the philosopher mechanics contained. Legislature called for the formation of a body assigned with the inspection of boilers, although the effectivity in preventing explosions by exertions of these bodies of inspectors were highly contested by proprietors and engineers. Many ship owners for example, considered that the law inhibited their enterprising activities and some of them actually were led to invest in other industrial branches. In the following years, between 1841 and 1848, some seventy explosions occurred and about 625 people died. Nonetheless, as Sinclair argues, Franklin Institute's scientific investigations did play a legitimizing role both of the institute and of the expansion in the use of steam engines for the public:

"From the beginning one other aspect of the research also captured the public imagination: namely, that the experiments were supported by an appropriation from the federal government. That fact alone gave novelty to the inquiry. The government was not in the habit of underwriting the research projects of private societies. Federal funding also conveyed the stamp of authority. Tax dollars seemed to legitimize the Institute's national standing, and many assumed that the organization had been especially selected to perform the research." [Sinclair, 1971: 191]

Another interesting point Sinclair makes is that American citizens of the nineteenth century knew all too well both faces of technological progress, both its bright and its darker side. These two aspects had been a popular subject for literature and painting, thus creating the metaphors of the era and by their own means stimulated the collective imaginary: "Romantic illustrations portrayed moonlight races on the Mississippi, with all their excitement. And other prints illustrated the great material prosperity inherent in the scene of a steamer loading hundreds of cotton bales for the textile mills of the North. The dark side had its own artistic mode. Steamboat disasters created a new literary genre, which soon encompassed railroad collisions, bridge collapses and other particularly affecting calamities" [Sinclair 1971: 172].

According to Mark Aldrich the outcome of the Franklin institute's investigations was not the elimination of the risk of explosions in American railways, but their contribution to the establishment of practices that indirectly led to the diminishment of explosions. Such practices that Aldrich refers to in his book Death Rode the Rails included the regular cleaning of the boilers, the vigilance of the engine-man in keeping the level of the water in the boiler high, as well as the establishment of investigations of the explosions by experts. As Aldrich argues, the drive for efficiency had been the one that led to major technological improvements that contributed to a higher safety on the railroads. "They were also far better designed and built, employed much more steel of higher quality, and were subject to more careful inspection and maintenance. These incremental improvements owed nothing to public policy; their combined effect was not only a more efficient locomotive but a much safer as well" [Aldrich 2006: 103].

Aldrich underlines the importance of technological development in the form of incremental innovations as the main cause for the improvement of safety on the American railroads, which he ascribes wholly to the manufacturers and builders of these technological systems. In so doing he underestimates the historical importance of state intervention in achieving a public consensus to the propagation of steam. The only intervention Aldrich considers to have been effective in the prevention of accidents on the railroads was the Federal Employers' Liability Act that was voted in 1908, because of the economic incentive that it provided to employers [Aldrich 2006: 207].

On the other hand Stephen P. Rice in his book Minding the Machine illustrates the damage explosions caused to the vision of the industrial society as a productive, progressive and well governed society. Explosions were according to Rice a common topic of discussions throughout Antebellum America. They were conceived both in material and in metaphorical terms. The appraised steam engine was accompanied by another metaphor that of the exploding steam boiler that was considered analogous to class conflicts and the division of labor that distinguished head from hand, intellectual from manual labor. As Rice shows, resolving the issue of explosions on a social level also meant resolving and managing the contrasts within the capitalist division of labor. Rice illustrates the importance of the investigation of the causes of the explosions and the attempts to prevent them as constitutive of the engineering discipline and also points to the necessity that emerged for the establishment of an educative system for the lower technical personnel.

In May 1817 the explosion of a steam boat near Norwich propelled the British Parliament to set up a committee that would end up not only investigating the causes of this particular case. It discussed also the issue of whether any state intervention was necessary at all. The committee examined experienced engineers, who proposed safety measurements they thought to be effective for the prevention of explosions in general. This was the first official delegation of cases of explosions. The committee decided for the registration of passenger steam boats, for the inspection in the construction and use of boilers and for the obligatory devices that a steam boiler should be equipped with and the measures proposed were similar in general lines with those proposed later by the Franklin Institute.

Interesting to notice was that Watt's preeminent engineer Sir John Rennie, acting as a representative of the class of manufacturers and proprietors held in front of the committee that no boundaries should be imposed upon the application of steam. He argued that such inspections would not safeguard the public against explosions, which were seldom and dispersed in the British case when compared to the American one, but would on the contrary forestall progress. According to John Burke the difference in the number of explosions between the American and the British steam boats was due to the double tonnage and capacity of the first.

Around 1851 Britain followed the French legislative exemplar, while in the United States another law was voted in 1852, which took into account the suggestions that were made by the earlier report of the Franklin Institute. This Act included the establishment of a specialized regulatory agency, the Steamboat Inspection Service. Ten years later the number of explosions had diminished in a large extent, although the hierarchy of the efficacy of the factors is still an object of opinion. According to Burke the steam boiler act was used as a precedent to state interventionism in the private domain in the name of public safety.

Bartrip's article *The State and the Steam-Boiler in Nineteenth-Century Britain*, is an evaluation of the relation between and the effects of the law with social and administrative changes in nineteenth century Britain. This article attempts to explain the resort to state interventionism during this period while being critical of other works that suggest it was a matter of the diffusion of the benthamist ideology or of an 'intolerable situation'. Statistics provided by Bartrip illustrate an increase in the numbers of explosions from the 1840s till the end of the century. Bartrip argues on the one hand that this increase is to a certain extent due to the more precise recording of explosions and accidents, while on the other hand it is also related to the diffusion in the use of steam. A noticeable remark is that the percentage in fatalities increased with a higher degree than the horsepower of the engines. However deaths from explosions remained less than those caused by accidents in the mines. The 1844 Act for the factories did not include anything related to steam boiler explosions. Until the 1880s the only authorized body to investigate explosions was the coroner and his action was limited in fatal cases.

"Given the geographical spread of accidents, the fact that most victims were of the working class, the universality of the steam engine and the desirability of steam power, perhaps it is not to be wondered that legislation was not forthcoming. […] [S]tatistical appreciation of the magnitude of a problem was by no means always a necessary prelude to social legislation" [Bartrip, 1980: 81].

Sir William Fairbairn, a preeminent British engineer, was the most devout adherent of legislative regulation concerning explosions. He advocated in favor of the formation of a company under the local authorities or under the government for the prevention of explosions and the investigation of the functioning of the steam engines. He argued that 'accidental death might often be valid in a legal sense, as a license for a repetition of neglect' [quoted by Bartrip from Fairbairn's correspondence with H. A. Bruce]. One solution to the problem at hand was given by hiring experts, but their calling rendered upon the jurisdiction of the coroner and in most cases was evaded due to financial reasons. For the same reasons the responsibility for carrying out such investigations became a controversial issue between the Board of Trade and the Home Office, as none of them cared to shoulder the expenses. Thus bureaucracy became a large impediment in the investigation of explosions.

In 1854 Fairbairn initiated the Association for the Prevention of Steam Boiler Explosions which came to be later renamed to Manchester Steam Users' Association and which by the end of the first year enumerated 271 manufacturers. However because of the absence of warranties and compensations from the part of the Association many manufacturers did not enter. This led to the establishment of the first insurance companies in the British Empire. While the Manchester Steam Users' Association remained reluctant in insuring boilers and engines until 1864, some of its members including Fairbairn set up the National Boiler Insurance Company. The company sought to deliver their services to the state for an annual reward, but the Home Office ignored the offer. According to Bartrip this move was also “a recognition of the supposed inevitability of government intervention and an effort to forestall the creation of entirely bureaucratic machinery” [Bartrip, 1980: 88].

In 1869 Manchester Steam Users’ Association and Henry Miller from the National Boiler Insurance Company, introduced the obligatory hiring of experts in the investigations of death caused by boiler explosions. They thought this could lead to sound verdicts and to the decrease of explosions but above all that it would prevent the state from intervening in their affairs. Fairbairn also came to change his mind about state intervention in the industrial domain and ranged himself with the formation of an association between manufacturers who would hire an investigator in order to check and report the condition of boilers and engines.

The first bill appeared in 1866 after coroner’s Robert Rawlinson report for an explosion in a textile manufactory. It was introduced to the parliament by three of its members, who recognized the necessity to enforce the Board of Trade and the body of investigators. The bill was withdrawn in 1869 and a year later another version appeared by a committee of experts whose integrity was contested by many inspectors. Most of those experts were themselves manufacturers from Lancashire while others were related to insurance companies. The president of the committee himself was a member of the Manchester Steam User’s Association.

The recommendations made by this committee varied from the endorsement of an obligatory inspection and the composition of an authority controlled by the government to the voluntary inspection that would be ensured by an act. Obligatory inspection was dismissed as it was considered to impair the manufacturers' liability and thus individual responsibility for the occasions of explosions was emphasized. After parliament delegation the bill was also withdrawn and it was not until 1882 that a law was finally voted.

The law of 1882 was an unassertive one, calling for the formal or informal investigation of explosions by the Board of Trade, and its scope was limited as it did not include domestic boilers, steam boat vessels and those used in the mining industries. Neither did it provide for any compensation for injuries or for those who lost their properties due to explosions. From 1884 onwards the Board of Trade published annual reports for the investigations of explosions which were rather descriptive and did not include further suggestions for the prevention of explosions. By 1890 the law was extended to include steam boiler categories that had been previously left out.

Bartrip also pays attention to the lack of interest from the part of the trade unions. He speculates that this fact was due to the wide range of the explosions in many branches that called for coordination. The Trades Union Congress (TUC) did in fact discuss the issue and came to the conclusion that explosions were mainly due to ineffective supervision or exaggerated use of the engines instead of bad construction. In 1875 TUC unanimously decided for the need of state intervention and asked for the certification of engine workers and boiler supervisors. This was constantly drawn to the parliament without being taken into consideration in the law for Boiler Explosions of 1882.

Concerning the decline in boiler explosions after the 1870s Bartrip underlines the role of technological improvements and above which the replacement of cast iron by wrought iron, the improvement in the techniques of clinching and pricking, and the replacement of wedge ends by flanges around 1866. Other factors that Bartrip considers to have played a part in this reduction were the improvements in the health system that diminished deaths to casualties, the improved precautionary standards in manufactures as a result of improvements in the educational system, private insurance companies – although they were effective for a twenty per cent of the total steam engines in use - and finally the enactment of the Employer's Liability Act.

In an overall evaluation of the relation between social reform and the legal system, Bartrip argues that industrialization had been the vehicle for all major reforms taking place during the long nineteenth century despite the reluctance for state intervention and the effectiveness of laissez-faire ideology. He also argues that the legal system was unable to conform to technological advancements in so far as it was incompetent of settling class conflicts and tensions. The result was a development in the collective resistance against capital, an increase in the laws for the protection of workers and an expansion of state interventionism even though at a practical level this did not have any considerable result. For example, although workers were juridically capable of suing their employers for casualties at work, in practice very few of them could afford legal representation. In the few cases that went to the courts, Bartrip says that most of the judges were positively disposed to employers and accused workers of being faddish. By the third decade of the nineteenth century employers had been totally dismissed from carrying out living expenses for their workers.

A technical article written by Ian R. Winship, *The Decline in Locomotive Boiler Explosions in Britain 1850-1900*, argues the statistical decline in locomotive boiler explosions to be related to the combination of technical, techno-scientific and administrative advancements that, to different degrees, led to the improvement of railway safety. Among the improvements stated we find the improvements in the construction of boilers, the use of wrought iron instead of cast iron, the effective management in the construction and mending of boilers, the recognition and acceptance of specific causal mechanisms as related to the explosions, and the improvement and specialization in safety mechanisms employed on locomotive steam engines which where previously not different from those on stationary steam engines. Winship also contests the effectiveness of boiler inspections, which he argues were adequate only for testing the impermeability of boilers.

In France under the napoleonean legislation an ordinance was redacted on October 1823 for stationary steam engines and steam boats. Preeminent scientists of the time like Arago, Biot and Dulong arranged detailed tables and prescriptions for steam engines. In J. B. Fressoz's paper, *Beck Back in the Nineteenth Century*, we read that a body for the surveillance of steam boilers was set up, in order to impose the regulations devised by the Academy and to collect information about the explosions, while the ordinance foresaw that any aberration from the rules would result to penalty clauses for the proprietor. The police was also involved given the task 'to maintain vigilance over steam boilers, their proprietors and their enginemen. This information was being collated by the French technical administration, for whom 'the whole industry, every steam boiler and every engineman, constituted a vast laboratory in which types of boilers, different safety devices, and the regulations concerning them could be tested in the real world.''[22]

Social historians have emphasized the importance of state regulations in cooperation with engineering experimental projects and accumulating in-use experience and technical know-how in the diminishment of steam boiler explosions. The set up of special regulatory state apparatuses for the case of these technological disasters, which the American congress initiated, is mentioned as the starting point of a series of regulations that made apparent, if not necessary, state interventionism in technological issues. As Rice has shown, settling the issue of boiler explosions in the antebellum America, which was anticipating a civil war that would settle the outcome of the conflict between, in the last instance, two different modes of production, one of the feudal mode popularly known as in defense of slavery, and another one of the capitalist mode, that was defending 'freedom of labor' (wage slavery) and industrialism, was above all an intervention in defense of a vision of industrial society as orderly and productive. We should I think also acknowledge the initiation of another pattern,

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[22] Jean-Baptiste Fressoz, *Beck Back in the Nineteenth Century*, pp. 342.

which was more in accordance with the laissez-faire ideology of Victorian Britain, namely private insurance companies, noting the fact that while in the case of the state, risk is differentially socialized (as to class) by a social distribution of the costs of regulation, in the case of private insurance companies risk is insured only after a careful consideration of profit making which calls for contracts of rules and conditions.

4. Bodies and Minds between Explosions and Automation: Computation, Regulation and the Rhetoric of Automation

Automation's finest hour in the mechanical era coincides with Watt's introduction on the steam engine of the governor, the par excellence mechanical control machine and closed loop feedback mechanism. The dark side of the long nineteenth century begins and ends with major control disasters. It begins with a great number of steam boiler explosions only to close with the emergence of another category of fatal accidents, flywheel explosions. These control related disasters exceeded, in terms of fatalities and of attracting theoretical consideration, all other steam engine related accidents. Boiler explosions as we saw, met their peak during the period of the gradual replacement of the low pressure by the high pressure engine, round between the 1820s and the 1870s, although such events kept occurring in low pressure engines as well but to a smaller degree and in the following period were steam remained in use in the twentieth century (e.g. in locomotives). Flywheel explosions, as it may be inferred from the discussions in the technical literature, became a matter of concern during the late nineteenth and into the first decade of the twentieth century. Their problematization seems to have emerged along with the pressing demand for ever higher speeds that were especially needed in the production of electrical power.

To start with, as we have already seen from the literature concerned with steam boiler explosions, efforts concentrated on what was going on inside the generator, i.e. the steam engine boiler. The pursuit was for a uniform and steady production of steam which had huge impacts on the uniform and steady working of the other part of the engine assemblage, the motor. In studying how the problem of steam boilers explosions was approached from the relevant discourses, the most remarkable thing we may notice is that the rhetoric of automation prevails even if automatic mechanisms appear to be related to the causes of explosions, either by themselves or in “human-machine” dis-functional couplings. Boiler explosions were thought as able to be solved by means of constructing a strong boiler, furnished with a minimum of necessary and well constructed self regulating devices while assuring that the engine-man and the fireman would constantly and uninterruptedly watch out for any irregularities. As I care to illustrate by combining the technical and the social, other factors were prevailing, which were primarily related to relative capital costs and investment.

Looking into the minutes of the examination of engineers that was conducted by the Select Committee of the House of Commons on Steam-Navigation in Britain (entitled ‘Abstract of Evidence before a Select Committee of the House of Commons on Steam-Navigation’), we may underline the following.

Not surprisingly, the major controversy in Victorian Britain had been a debate over the use of low versus high pressure engines (i.e. condensing vs. non condensing respectively), the safety of both was thought to be a matter of construction and supervision. The divergence between the opinions of the examined engineers were polarized between the Cornish engineers of the mines, who were in favor of the high pressure engine and those coming from the North and Midlands who favored the Watt type condensing low pressure engine. It was the very particularity of the process in which the steam engine was called to work that defined the appropriateness, both in quality, efficiency and economy. A. Nuvolari and B. Verspagen have studied the diffusion of the high pressure engine in nineteenth century Britain by means of an innovation studies toolkit. In so doing they emphasize the controversy between high and low pressure engines. One thing that concerns me here is the absence of governing in high pressure engines. The authors state that the length of the stroke in the high pressure engine 'could be regulated quite easily by the tappets which controlled that descent of the piston.' [Nuvolari and Verspagen, 2005: 26] Their study illuminates the fact that for the purposes of water drainage in the mines of Cornwall, the irregular hand fixed working of the engine was sufficient, as no high accuracy was needed, and additional higher accuracy meant investment of capital, which made the engine-man governed engine the most economical: 'Further technical problems hampered the adoption of high pressure steam expansively in engines employed to power machinery. The Cornish practice of high practice [probably *pressure* meant instead] expansive working could not be easily transferred to mill operations, where the application of the steam engine to industrial processes generally required a smooth piston movement.' [ibid, 2005: 20] [23]

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[23] A.Nuvolari and B. Verspagen, "Unravelling *the Duty": Lean's Engine Reporter and Cornish Steam Engineering*., European Historical Economics Society, *Istanbul*, September, 2005. (http://www.ata.boun.edu.tr/ehes/Istanbul%20Conference%20Papers%20May%202005/Istanbul.pdf).

Second, there was a general disagreement between engineers as to the use of wrought or cast iron for the construction of the boiler. Third, almost all agreed that two safety valves should be attached to the boiler, one being held locked and only to be adjusted by the proprietor, although reliance to the safety valve was by many contested as a truly safety measure especially under heavy pressure and its proneness to malfunctions was also noticed. Fourth, all held that a steam gauge (a mercurial column) was indispensable for the engine attendant to have a continuous overview of what was the pressure inside the boiler, although this device's accuracy was also contested and its malfunction related to accidents. Finally, all agreed when asked for the importance of the engine worker in terms of safety, while many blamed them for the majority of the explosions.[24]

The same more or less as we have seen were also suggested by the General Report that the Franklin Institute had put down in 1831, although as we already accounted for economic reasons, high pressure engines in the United States were undebated. By the beginning of 1831 a series of experiments were completed under the surveillance of A.D. Bache, Secretary and Director of the Franklin Institute of the State of Pennsylvania. In summarizing again the factors that were found to be correlated with the explosions were: a) faults in the boiler construction, b) having too little water in the boiler, c) overloading the safety valves or holding them down in order to increase speed, which was a common cause of explosion in steamboats and steam locomotives, and d) some

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[24] 'Abstract of Evidence before a Select Committee of the House of Commons on Steam-Navigation' held on 8 May 1817, in Partington, 1822: 71-119.

combination of an engineer's neglect, ignorance or 'criminal misbehaviour'. The general report of the Committee highlighted that "explosions were often produced because safety devices were misused or failed to work properly".[25] They also showed that unlike common sense, explosions could occur while the boiler was full of water. This fact illuminated the importance of the homogeneity in the burning of the fire that was used to heat the water in the boiler, which rested on the virtuosity of the fireman. While the report of the Franklin Institute committee emphasized the gradual accumulation of pressure with the failure or abuse of the safety valve as the most common cause of boiler explosions, other relative factors that can be reconstructed by the primary literature also involved occurrences of explosions due to the overheating of boiler plates, due to either shortage of water or to an accumulation of sediment, followed by letting in water.[26] The labor of cleaning the sediments in the industrial settings of Lancashire is described in details in the following passage:

"It generally happens, that the spare boiler, if there be one, stands immediately adjoining those that are constantly at work, and the heat from the adjacent boilers and brick work renders it quite impossible to clean out the flues without an amount of individual suffering which few people have any idea of. The ordinary climbing boys are not generally employed to sweep the flues of a steam engine boiler in a factory; a strong man usually is required for the purpose. Quite

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[25] Bruce Sinclair, Philadelphia's Philosopher Mechanics, p. 180.

[26] For a summary of experimentally proven causes of boiler explosions since the 1870s see, J. R. Robinson, Explosions of Steam Boilers, 1870.

a different sort of manual process is necessary than that used for sweeping a common house chimney; indeed the latter must be, comparatively, a pleasant occupation. In the former case the man has to *worm* himself through the flues, in a horizontal position, pushing before him the contents of the flue, or 'flue dust' as it is called; which is not soot, but a heavy kind of deposit." [Armstrong, 1839: 231]

Low water in the boiler could also be the case of the presence of a defective feeding pump, or of a failure of gauges, as the General Report also described: "At best, when the water is tranquil within a boiler, they only show, roughly, the position of the water line; and when it is above the highest cock, or below the lowest, they fail entirely." [quoted in Hunter, 1985: 347]

From Louis Hunter's Steam Power, we read that in practice the safety valves would defeat the end with which they were assigned. In the first place there might be wrong proportions between the valves and the boilers capacitance. Second, misuse of the valve or corrosion could render it inactive. Third, many manufacturers and proprietors were tempted to 'set the value at an unduly high opening pressure or even to add extra weight to the end of the lever'. 'Steam wasting', as Hunter argued, 'at the steam valve was fuel money out of the owner's pocket'. When business expansion called for an increase in power needs, 'it was easier and cheaper to obtain it by boosting steam pressure and 'adjusting' the safety valve than installing a new and larger engine and providing increased boiler capacity.'[27]

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[27] Louis Hunter, Steam Power, p. 344.

From these we may discard to the level of rhetoric any essentialist view of the safety valve as a self regulatory, automatic device: “The safety valve being an object of considerable importance, both as regards the utility of the engine, and the preservation of those connected with its management, much attention has been given to its construction […] The lever and balance ball which form this apparatus, would at all times be effectual were they not liable to be fastened by the corrosive nature of the materials of which the valve is composed and, what is worse, their pressure altered by the addition of more weight. This, however, as too frequent experience has shewn, is continually the case, the engineer having more regard for the full performance of his machine than for his own safety or life; and to the overloading of this valve, these accidents may be principally attributed.’ [Partington, 1822: 67] And also, in A Descriptive History of the Steam Engine written by the British civil engineer Robert Stuart: “The introduction of the *Safety Valve* [by Papin] may even now be considered as one of the most important improvements made in steam apparatus; and the want of which long and powerfully retarded the introduction of Savery’s engine” [Stuart, 1824: 53]

Following the canonical history and treatises of engineers of the nineteenth century, we may be informed that introduced with the aim of controlling steam pressure inside the boiler, the safety valve, was a mechanism invented by Denis Papin in 1681 as a pressure regulator for pressure cookers, and used by him on a steam boiler as early as 1707. ‘It consists of a weight loaded valve in the boiler wall which is forced to open by excessive steam pressure until the surplus steam is released’ as Otto Mayr informs us, while adding that in contemporary engineering terms, 'it represents a closed loop with negative feedback'.[28] The safety valve was however able only to attain a static equilibrium, in contrast to governors who could provide for dynamic equilibrium. Hence the market self regulation analogy. Following this historical account of self regulatory, automatic mechanisms out of their context of use, both the wider technical and the social, and treating them in functionalist terms leads us to oversee the steady occurrence of boiler explosions.

The Working Engineer's Practical Guide, written by Joseph Hopkinson, offers us an in-use approach to the several gauges and safety devices. Hopkinson warns the managers of steam engines that they should be reluctant when using self regulating apparatuses: "If a self regulating feeding apparatus is used, it should be closely watched, and on no account be implicitly trusted. […] In most cases, with high steam they are positively dangerous, and should not be trusted. […] Safety valves, as commonly made and understood, are valves simply for the letting off of steam under certain calculated circumstances of pressure. Thus constructed are, in fact, only steam valves, and not safety valves." [Hopkinson, 1866: 2-3] Moreover, Hopkinson moves on to warn the working engineer that most of the various forms and makes of steam gauges, 'are nothing better than philosophical toys.' [ibid. 6]

Second, we may notice that while all self regulatory mechanisms had to be computed by the top engineers in order to make the necessary adjustments of pressure, in the official proceedings of the examination of boiler explosions, the

[28] Mayr, 1971: 70.

heads of the technical division of labor are absent, while the lower technical personnel appears to bear the whole responsibility of the working of the engines. In contrast, in all treatises of steam engines top engineers' achievements are properly appraised as well as recorded for justifying or contesting patent rights, while manual labor is on a steady base concealed.

Notably every treatise on the steam engine and its components was accompanied by tables of computations, which related horse power of the engine, fuel consumption, numbers of strokes, and other measurable quantities that were used for construction of components, adjustment of parts, calculation of efficiency in relation to economy etc. Maybe the most paradigmatic of the state of the art computation techniques of this period written in 1827 was John Farey's A Treatise on the Steam Engine, were the slide rule is presented as an indispensable computing artifact for making all kinds of computations for the construction and adjustment of the parts of the steam engine. Farey devotes more than forty pages in illustrating how it should be worked, from how one should hold it to how its indications should be grasped. Moreover he has included in his treatise exemplary calculations of every component of the steam engine by the use of the slide valve. Farey also makes explicit mention to the importance of the use of another graphical instrument, the indicator, which was used to provide diagrams of pressure and volume, that made visible the invisible processes in the movement of the piston: "The resistance with which the engines are loaded, is rarely known, for the notions of the people who usually have the care of them, are very fallacious; and even reputed judges of engines are frequently deceived in their opinion of the resistance that they are actually overcoming; for it is only by frequent trials of different engines with an indicator, so as to obtain an actual knowledge of their performance under different circumstances, and an accurate observation of all the apparent symptoms during such trials, that an engineer can acquire the tact of judging with tolerable accuracy what load an engine is working against." [Farey, 1827: 636] The extent to which the indicator was used has been said to be restrained, from what I have read because it remained one of Watt's industrial secrets, and another reason given for this fact by Mayr in *Yankee Practice and Engineering Theory* is that before Richard's improved indicator, 'indicators at that time were clumsy of construction and seldom used'.[29]

Third, both in cases of steam boat racing and in boilers exploding, the carelessness of the engine-man has been notably stretched, while proprietors' interests are barely discussed. Robert Armstrong, a practical engineer who appears to have been sensitive both in supporting state legislation as well as a defender of the low pressure steam engines, wrote: "It unfortunately happens that, in this manner, the interests of the manufacturer and the real interests of humanity do not agree; for it has been incontestably proved, that a strong draught is extremely favourable for saving fuel, as may be judged from the fact, that the time for getting up the steam have been in some instances reduced from upwards of an hour, to twenty or twenty five minutes, and although the saving of coal has not been in any thing like that proportion, yet it has been very considerable." [Armstrong, 1839: 234]

[29] Otto Mayr, *Yankee Practice and Engineering Theory*, pp. 576.

We may also take time here to reconsider two interventions in the proceedings of the House of Commons committee on steam navigation examination that demand special attention. The first is from the examination of Watt’s preeminent engineer Sir John Rennie, which we discussed earlier and the second case is an engineer sent by three proprietors of the largest mines in Cornwall who ‘wished to state their hope, that the Legislature would not interfere to prevent the use of high pressure engines, either on board boats or in any other way’ [Partington, 1822: 115]

In contrast the Scottish working engineer and boiler expert, Robert Armstrong who had been occupied with boiler explosions hesitantly used the words of an anonymous reader’s letter to a newspaper in closing his treatise on steam boilers, to address the need of state intervention in the case of boiler explosions: “I hope sincerely that some of your numerous readers will now be awake to the importance of this subject. Government, I see, has thought the explosions in coal mines deserving its notice. Steam boilers have probably caused as great a destruction of human life within the same period; and, therefore, seem equally deserving its attention. We hope the subject will be attended to by the legislature, and every engine-man compelled to keep his boiler both clean and strong. S.P.” [Armstrong, 1839: 263-264]

What I care to illustrate by making the above points, is that the struggle for regulation, from the point of view of proprietors was never an issue in-itself but an issue relative to profit making. Contrary to the common sense, self regulation seemed to consume power instead of providing for even greater productivity. It was only in cases that engineers had empirically proven savings, in the rate of profit when variable capital increased as to constant capital or in the case of manufactures where quality of products was all too important, that regulation was favored. Moreover it depended upon the particularity of the engine design. From the point of view of engineers regulation was provided by means of computation, computing the particular analogue devices which ought to be proportional to the engine assemblage and its load. From the point of view of the lower technical strata regulation had nothing to do with inherent properties of engine components but needed constant and undisturbed labor, by means of hands. As we discussed in the previous section, these workers often paid off calamities, whatever their causes, with the cost of their own bodies which were mutilated if not killed. Their bodies were the first to go down. As Rice has shown, the gradual elevation of the social class of engineers during the nineteenth century as a middle class stratum, where doctors and civil servants 'inhabited', was due to their nodular position: '[the professional engineer] was the disinterested authority whose special knowledge meant that his directions should be heeded for the safety of all society.' [Rice, 2004: 144] The rhetoric of self regulation, automation during the mechanical era, even if it is not coined up in terms of feedback involves a representation of computation as that what mattered, while downplaying the importance of manual labor: "In this sense, the negative feedback circuit appears to be a dematerialized version of the real circuit, which, connected to the real circuit, is like a mind in relation to a body. Without an ideology that presents the process of computation as determining the process of regulation, the separation between signal and load (mind and body) that defines regulation by negative feedback would have been impossible. In other words, from the steam engine onwards, the history of regulation by negative feedback (that, to repeat, underlines the drive for automation, technical regulation, circuit self-regulation) is no different than the history of promoting computation as what matters. Unsurprisingly, this same history brings us from the cybernetes to the cyberspace." [Tympas, 2001: 309]

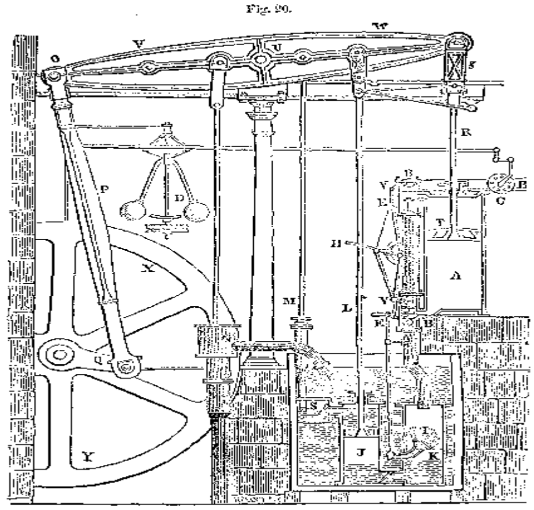
From the problematization of steam boiler explosions, it is also evident that the solution was thought to be found only by focusing on the generator, on the devices and the materials used for the construction of boilers. Through the discussions over boiler explosions we may infer by and large that they were maintaining that if production of steam was made uniform then consumption on the moving parts of the engine would be equal.

By the end of the nineteenth century steam boiler explosions have been shown to have declined. When explosions ceased to manifest themselves in the boilers the problem was in turn manifested on the other part of the steam engine assemblage, the motor. With increasing speeds, the governor was proven unable to maintain the dynamic equilibrium between the boiler and the motor. Explosions of parts of the motor with most common and dangerous the flywheel explosions were introduced with the increase of speed in the second half of the nineteenth century: "With rising speed, conventional engines ran poorly; they became increasingly noisy until they shook violently. Then there was the danger of runaway speed. If for some reason (e.g., a broken drive belt) the governor lost control and the steam valve fell into wide-open position, the engine raced to frightful speeds, often to the point where the flywheel distingrated [disintegrated] with violence (after boiler explosions, this was the most common accident in steam engine operation)" [Mayr, 1975: 575]. Noticeably, Mayr imputes these accidents to operation.

The advantage of the Watt governor in delivering a more uniform speed and working of the steam engine was counterbalanced by the fact that, being connected to the throttle valve, which opened and closed proportionally in an "all or nothing" manner, it could not deliver an economic cut-off for the admission of steam into the cylinder. We already discussed the issue of using a governor or leaving the cut-off point to be adjusted by the engine-man. In this passage Farey describes the connection between the governor and the flywheel in a Watt steam engine: "This method of regulation [the engine-man can turn the valve at any required angle in order to obstruct the passage] is sufficient for many engines; but when the steam engine is employed to drive machinery, in which the resistance is variable, and where a determinate velocity cannot be dispensed with, Mr. Watt applied the revolving pendulum or governor, in order to regulate the opening of the throttle valve according to the velocity with which the engine is intended to move. […] As the governor derives its motion from the flywheel, it must partake of every increase or diminution of velocity which takes place; but the pendulums being freely suspended, will fly out from the vertical axis to a different distance corresponding to every different velocity, so as to assume that the position in which the weight of the balls, and their centrifugal force, *will* *exactly balance each other*. As every alteration in the position of the pendulums produces a corresponding alteration in the opening of the throttle valve, the governor will keep the engine nearly to one regular motion. For whenever the engine exceeds that regular motion, the pendulums of the governor by expanding, will close the throttle valve and diminish the supply of steam, until the motion of the engine is reduced to proper speed." [Farey, 1827: 459; my empasis]

The defect of the proportional action of the Watt type governor was according to the canonical history of the steam engine governor partially remedied by the Corliss' automatic cut-off mechanism, which connected the governor with a gear mechanism instead of the proportional throttle valve. However, the Corliss' steam engine assemblage could be efficiently worked in low speeds, and in this Porter's success in governing high speeds was commercially celebrated.

Fig. 20.



Watt's governor embedded on the reciprocating engine and connected to the flywheel and throttle valve. Noticeably, the boiler is not shown here. From John Bourne, A Catechism of the Steam Engine, 1854 at www.gutenberg.org/files/10998/10998-h/10998-h.htm.

In most high pressure versions of the steam engine, as we noted earlier, the governor was dispensed, while regulation was wholly placed upon the flywheel (and of course the attendant): "The action of the fly-wheel, is to equalize the force of the circular motion, and to impel the machinery in the intervals when the planet wheel is above or below the sun-wheel. […] The fly-wheel is urged into an accelerating motion at these favourable positions, and when the position of the planet-wheel is less advantageous, it will continue to turn all the machinery, by the impetus of its accumulated motion. The force which the planet-wheel can exert to turn the sun-wheel and fly-wheel varies continually, being nothing when the piston is at the top or bottom of its course, but afterwards it decreases again to nothing at the end of the course. [Farey, 1827: 450]

Stuart Bennett in The History of Control Engineering 1800-1930 quotes a passage of the letter T. Patterson sent to *The Engineer*, published in 1868, which contests the in-use effectivity of the Watt type governor: "[D]uring an experience of 25 years I have always found the old-fashioned pendulum governor, as used by Watt, to be quite sufficient to regulate the motion of the steam engine, yet from want of attention to the mode of adjustment the presence of 75% of these governors is more ornamental than useful. Hence the great influx of patent and other governors, some of which are neither ornamental or useful…" [Bennett, 1979: 24] Bennett continues to report some estimations made by A. T. Fuller, another historian of control systems, which show that in 1868 over 75 000 governors were in use in England. In referring where they were used he includes 'steam and water turbines, telegraphic apparatus, the phonograph, oil and gas engines and speed control of electric motors' [ibid. 24]. The endurance in the use of the Watt governor, in its imperfectness, is credited to its simplicity.

Two editions of The Electrical World published on 20 October and 24 November 1894 respectively, contain discussions of flywheel explosions under the heading "Flywheel Accidents in Power Stations". These discussions were letters sent in response to the letter of a Mr. Coykendall addressing the issue of flywheel explosions in a railway company. Almost all of the responses call attention to the governors' malfunctions as the main cause of flywheel explosions. R. H. Thurston responded that 'In such accidents I have known, of the class referred to, the engine is found, after the break down, to have had its governor deranged and, presumably, this has been the cause of the accident. A belt slips or breaks, or the key comes out of the governor pulley, or the engine is relieved so suddenly and completely of its load that the charge of steam just taken into the cylinder is sufficient to accelerate its speed to the danger-point with a weak and faulty wheel. The conditions of operation of the engine in electric light and power stations are peculiarly favorable to the production of such accidents. The enormous variations of power, often from no load to an excessive load, in an instant, and the constant changes of load are sure to result in a constant jerking and shaking of the whole machine, and especially in the governor system. And this rattling of the governor pulley, if the key be not driven hard, and the shaking of its belt, make it certain that, sooner or later, something will get loose. If it shakes out the key, the result is pretty certain to be disastrous; if the governor belt simply slips, danger follows, if not disaster; if the belt breaks, the engine is gone.'[30] Thurston still focusing only to the mode of governance used advocates Porter's loaded governor, as a replacement that would evade serious risk. He also favors the replacement of the drop cut-off (throttle governing) by an automatic cut-off (Corliss' coupling of the governor with the cut-off gear). Like in the case of steam boiler explosions, in flywheel explosions the same structural reasoning is developed in the remedies proposed. Another sender, C. E. Emery, notes that he has personally investigated many cases in which flywheels were disrupted and he was convinced that 'the accidents were due to centrifugal force arising from high speed, and necessarily involved improper action of the governor'. He then quotes the words of 'some wag', who had said of automatic apparatus, that 'The better and longer they work the more dangerous they become'. He then moves on to agree by writing that 'steam engine governors work so perfectly for very long periods that eventually they become neglected in some detail'. This could be taken as illustrating a direct effect of the ideology of automation in producing real, material explosions that killed, mutilated and scorched bodies through trusting their 'automatic' pledges and producing negligence whether in looking after its working or in its maintenance. But we should be careful in drawing quick conclusions the ultimate and practical reason being, since top engineers knew their shortcomings, evading investing capital in accurate and effective regulation. Why not otherwise incorporating the latest

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[30] "Flywheel Accidents in Power Stations", in The Electrical World, Vol. XXIV, No. 16, 20/10/1894, pp. 401.

supposedly safe automatic mechanisms of their time or seeing to the maintenance of the existing ones?[31]

As late as 1941, inadequate maintenance of governors is indicated as a major cause of malfunctions in electricity supply companies: 'Several systems [electricity supply companies], which have investigated governor performance at various times, have been convinced of the troubles can be laid to inadequate maintenance of the governors.' [Bennett, 1979: 24]

In the cases of flywheel explosions, another controversy structurally analogous to the low and high pressure steam engine controversy is presented, in terms of low versus high speed as to safety, economy and efficiency. In the following edition of The Electrical World other causes are also included, while governing remains preeminent cause. "The accidents which have come to fly-wheels are much varied in their nature; usually they are due to accident to the governor which permits the speed to accelerate to such extent that the centrifugal force becomes sufficient to rupture the wheel; often-times they are due to defects in materials or to faulty construction of the wheel itself. In one case, with which the writer was acquainted, the accident was caused by a defective shaft.'[32]

As with the safety-valve in the case of steam boiler explosions, the governor's inability to regulate is 'unraveled', while at the same time the

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[31] Ibid. 402.

[32] "Flywheel Accidents in Power Stations", in The Electrical World, Vol. XXIV, No. 21, 24/11/1894, pp. 550.

attendant of the engine becomes here also a source of erroneous behavior. I chose to close this section by this exemplary passage written by R. Fleming of the U.S. Navy Yard, which explicitly questions the practice of dynamo builders to put many switch boards thus rendering the attendant-machine interaction even more dangerous: ‘Suppose the load increasing, and it becomes necessary to put in a fresh unit. The engine is brought up to speed. The dynamo attendant adjusts his voltage to that of line (or thinks he does). But it so happens that the E. M. F. [electromotive force] of the fresh dynamo is too low when he closes the switch. The result is a large deflection on the ammeter. The attendant, unless he is cool-headed, immediately adjusts his shunt rheostat violently, and most likely will turn it the wrong way. By this time there is a squealing of belts, the ammeters are demoralized, and the man crazy. As a last resort he will throw the switch on the face of the rheostat and break the shunt circuit through the lamps. (Why dynamo builders put a switch in the shunt circuit is more than I can understand. It is a source of the greatest danger, and altogether unnecessary.)’ [33]

[33] Ibid. 551.

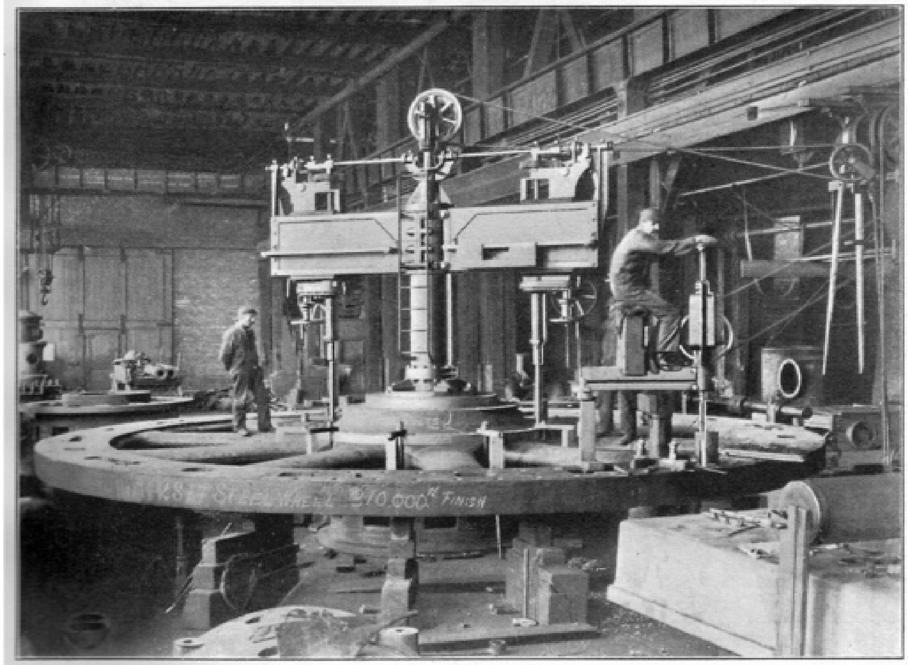

Fig. 3 Drilling and Reaming the Bolt Holes.

This photograph of the construction of a massive flywheel at E.P. Allis Company was published in American Machinist Magazine in 1900. The flywheel was for one of the 11 engines being built for the new power house of the Metropolitan Street Railway Company in New York. (http://www.practicalmachinist.com/vb/showthread.php?t=112618)

5. By way of conclusion: 'Arbitrary' Analogies to Be Worked

…a freedom still enmeshed in servitude

Hegel, Phenomenology of Spirit

In this thesis I studied how mechanisms of automatic control of the mechanical era, back then referred as regulators, self-regulators, self-acting or automatic mechanisms were designed, constructed, used, maintained and conceived in order to attempt a historical re-consideration of boiler and flywheel explosions, the latter having been a problem that outflanked engineering settings to come under social consideration. The interest in the development of mechanical self-regulatory mechanisms met its peak during the high time of the First Industrial Revolution, and it is during the same period explosions become noticeable in public terms due to their fatal and horrific effects. It is in rough terms the period historians have called the long nineteenth century.

In navigating myself through the primary literature available to me, I studied the history of feedback by Otto Mayr and the history of control engineering written by Stuart Bennett both providing detailed analyses of these mechanisms in an inexplicit comparative manner. These authors offer us invaluable insider's insights in comparing the way self-regulatory mechanisms were viewed with the scientific engineering knowledge of their times, and in so doing they remain 'biased' towards institutionalized engineering knowledge or engineering as science, and in many cases do not cut ties with their historical actors rhetoric. Next to this, the questions they have asked were formulated during the 1970s and 1980s, the period of the early development or of the revolution of information technology and a period when the popular imaginary had been much ingrained in cybernetic(ians') visions. As such they have given us a history of feedback and control engineering that starts from the steam engine governor, as the artifact whose behavior attracted scientific interest and the predecessor of control mechanisms to come. According to this line of historical reasoning the steam engine governor has, above all by means of the formation of a scientific, i.e. mathematical theory of control, successively led to the emergence of more precise mechanical, electrical and electronic control mechanisms.

The problem of boiler explosions was thought to have been solved by the time the Second Industrial Revolution, i.e. the electrical era, begins although it has been given two different historical explanations. If we extent to its limits an internal history of technology point of view, explosions would be considered solved (that is reduced to a tolerable degree) by means of progress in theory, design and construction of self-regulatory mechanisms. As a matter of fact historians of the steam engine of the 'Steam Age' do argue this. From a social history point of view that treated the case of explosions, it has been thought solved by mechanisms of state regulation, which were developed exactly for the prevention of explosions. In turn I tried to show the limits of the feedback schema as supposedly providing both for market regulation and for technical regulation, by viewing it from the perspective of steam engine explosions where both the market and the technical self-regulation have been contested.

As it follows from this examination, Otto Mayr has been right in drawing corresponding lines of the early conception of technical self-regulation (the first period of mechanical control) in terms of balance and equilibrium that corresponded to the liberal economic theories of supply and demand of the same period. These theories, however, of technical self-regulation and of economical self-regulation, remained incompatible with occurrences of steam engine explosions -over-pressure (boiler) and over-speed (flywheel) explosions- and economic crises in historical capitalism respectively, and were unable to be explained by a satisfactory account of their causes. As I see it this is due to their standing at an intersection with the social.

In the economic context, the law of Say, which both schools of classic and neo-classic economics share, thinks of the existence of some mutually negated imbalances. According to Say's law a product is not created earlier than the moment that it creates a market of other products of value in sum equal to its own value. Every increase in production will automatically create an equal in size demand, as the products are 'paid' by other products. The producer sells in order to buy. Thus, some products remain unsold just because some other products have not yet been produced. This means that the consumptive ability of society necessarily increases with every increase of its productive capacity.

Symptomal analysis provided by Louis Althusser and others has actually given a method of reading widely used in literary critic studies.[34] As Milios et al., have suggested in their consideration of capitalist economic crises we should

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[34] Louis Althusser et al., Reading Capital, New York: Verso, 1979.

consider over-accumulation crises as over and above emerging under the action of "absent causes". Overaccumulation crises should not be identified neither with the law of the falling rate of profit, nor with the supposedly intrinsic to the system tendency of the working classes for under-consumption, but on the contrary, they should be perceived as a conjectural production of commodities (means of production and means of consumption) in such quantities and prices that lead the process of accumulation and the expanded production of the total social capital to decelerate or intercept and, at the same time, the rate of profit to fall.[35]

I suggest that we might consider thinking of boiler and flywheel explosions in similar terms. They are not the result of a visible and predictable –thus manageable- cause as in example disproportions between production and consumption of steam, or merely of some automatic machinery malfunction, nor the negligence or drinking of a worker. Rather these are their forms of appearance. Instead I suggest that we should acknowledge their being the consequence of the fusion of the sum of social contradictions, emerging through capitalist development itself, which in the last instance, are determined by class struggle, i.e. the degree of exploitation of the labor force.

As to the ideology of automation, I care to discuss it for a while here by providing some more recent examples from control engineering. In present engineering terms, control mechanisms are distinguished between performing

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[35] Milios, J., Dimoulis, D. and Economakis, G., Karl Marx and the Classics, Burlington: Ashgate, 2002. Here referred to the greek edition Part IV, chapter 9, For a Marxist theory of "overaccumulation crises" , pp. 285-297.

open and closed loop control, only the later falling under the category of negative feedback. Open loops can control their input but they do not take into account the output to adjust their future performance. The distinction between open and closed loop control entails an axiological hierarchy, according to which feedback loops, i.e. closed loops are more *intelligent* than open loops. In-use however this essentialist hierarchy is contested. And it is in the same line as another later essentialist distinction, the one between the analog and the digital that is used by the canonical history of computing to mark the threshold to information technology.[36]

Far from being wiser in an in-use approach, it is the very particularity of the process that determines which kind of control is more appropriate. In some cases open loop control is preferable as to safety and stability even if it pays the price of accuracy, especially since closed-loop control is a lot more prone to instabilities. Nonetheless an experienced operator's response could be much faster and thus preferable than both. As a contemporary control engineer underlines: 'Even feedback controllers must operate in the open-loop mode on occasion. A sensor may fail to generate the feedback signal or an operator may

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[36] See, Tympas, Aristotle, 'Perpetually Laborious: Computing Electric Power Transmission before the Electronic Computer', International Review of Social History, Volume 11, Supplement, 2003, pp. 73-95. And for a philosophical discussion of the analog/digital dichotomy in cybernetics see Pias, Claus. *Analog, Digital, and the Cybernetic Illusion*, Kybernetes, 33/2, 2004. [special edition in memoriam Heinz von Foerster].

take over the feedback operation to manipulate the controller's output manually.'[37]

We noticed in passing the essentialism that is clearly exemplified in the glorification of the steam engine governor as part and parcel of a tradition of intelligent machines that start with *cybernetes* (the greek name of the steersman from which the Latin word governor derives), a name given by James Watt, to come to the cyberspace. A discussion of the definition of intelligent control took place in December 1993, under the heading *'DEFINING INTELLIGENT CONTROL'*, Report of the Task Force on Intelligent Control, arranged by the IEEE Control Systems Society. Watt's fly-ball governor, by the way, found its way in a genealogy of intelligent control into these discussions. How did these experts on intelligent control define their subject matter? Many opinions were expressed, but in defining intelligence most of the participants tended to support A. Meystel's suggestion: "The definition of intelligent control should be based on the properties of intelligence as we understand them rather than the virtue of using some particular hardware components." [Antsaklis et al., 1993: 22]

The attempt to escape a self-referential, scientific type of definition and to draw correspondences between human and machine makes such an analogical definition to work in a double-way manner: it transfuses human properties to the machine, hence constituting the android its uttermost extension, while taking for granted such properties as inherent to a human individual, absolute proprietor of

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[37] See, Vance J. VanDoren, *Open-loop control offers some advantage*, Control Engineering, 10/1/1998.

himself and of a free will. In the case of machine naming, it is interesting then to notice the slippage in terminology from governor to servomechanism and back to cybernetics. Or additionally another recurring couple, the master-slave terminology, from clock mechanisms in early twentieth century to hydraulic systems and to computer terminology, or even the term 'robot'.[38] In these examples naming is not merely a scientific convention recognized as such, but names in these examples are rather codified manifestations of historically specific techno-social relations.

Katherine Hayles in How We Became Posthuman has studied by means of a discursive analysis the struggle between Norbert Wiener's humanistic conception of a liberal subject and the implications of his cybernetic theory which implied the dependency of the 'subject' upon its environment through its communicational exchanges with it. Escaping an analogical human-machine definition, but providing with a 'scientific', universal definition of feedback Wiener was caught up in a strange contradiction.

Looking at the first pole of the human-machine couple, we may notice that the problematization of the liberal subject invested with a free will has spurred one of the major philosophical controversies of the twentieth century. The problem of the subject and of subjectivation (in French coined up as

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[38] See Ron Eglash, *History of the phrase "master-slave" in engineering terminology*, at www.ccd.rpi.edu/Eglash/temp/History%20of%20the%20master-slave%20terminology.doc. And by the same author, *Broken Metaphor: The Master-Slave Analogy in Technical Literature*.

assujetissement) which puzzled intensively the French intellectual scene from psychoanalysis to philosophy, amidst the twentieth century has been given a 'dialectical' treatment. For Michel Foucault *assujetissement*, i.e. subjectivation is simultaneously a process of becoming a subject and of being subjected. If we keep our focus to the social context ignoring for the purpose of our analysis Foucault's late studies of technologies of the self, institutions – frozen technologies bearers of power relations in Foucault's terminology - must enter the picture. For Louis Althusser, becoming a subject is a process enabled through *interpellation*, through the calling or the naming. This takes place through or rather within ideology, but an ideology conceived not as a false representation of a world consisted of platonic ideas, but as embedded in ideological state apparatuses. Althusser had fought to think of the formation of the subject through ideology in terms that resembled Blaise Pascal's 'kneel down, and you will believe'.[39] Through bodily gestures and postures, formatted in disciplinary techniques like Foucault showed of Bentham's panopticon, or regulatory state mechanisms like the police, persons become subjects. But these subjects are also and always subjected subjects. If further we accept that meaning is produced in an inter-subjective manner, it is then through relations that subjectivation takes place.

To the well-acquainted reader, the similarities of feedback with dialectical reasoning are quite obvious. An unhistorical universalization of dialectics in

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[39] Louis Althusser, *Ideology and Ideological State Apparatuses*, Lenin and Philosophy and Other Essays, Monthly Review Press 1971.

philosophy has been the root of one of the biggest debates of the twentieth century, which had huge political implications especially during the Cold War years. Still both philosophers we mentioned above never stopped underlining explicitly and methodologically the importance of grounding philosophical practices on historical consideration. Similarly, as I wished to have outlined in this thesis an unhistorical universalization of feedback as reflexivity or nowadays virtuality, which appeared as a phantom that kept haunting and fascinating Wiener and all others involved with the theoretical consideration of feedback, may well be classified in the history of the '*Holzwege*', the paths that lead nowhere.[40]

We may think Hendrik Bode's recognition of his mixed emotions when struggling to regulate with an electronic feedback amplifier, as such kind of a struggle as that described in terms of subjectivation.[41] Bode could not cope with the problems of stability that kept occurring each time he tried to regulate (materially) by using feedback. In these material terrains relations unthinkable from a theoretical-mathematical-deductive point of view (lets say, academic engineering), as that held by Wiener and Bode, were 'super-imposing'. But to explain the material limitations of regulating by feedback we should resort to a historically specific account of such attempts that brings forth institutional imperatives and practices caught up in wider social networks. The relative

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[40] For an analogical co-consideration of cybernetics and dialectical materialism see, Guillaumaud, Jacques. Cybernétique et Matérialisme dialectique.

[41] See Mindell, David A. *Opening Black's Box: Rethinking Feedback's Myth of Origin*.

pyramidal divisions of labor that are being formed along, in their relational interplay subjectivize and subject historical actors, which manifest themselves for the human by the activation of ideologies registered in rhetoric, for the non-human by being fetishized and black-boxed.

If we care to think of the agency of non-human actors in our case, it needs not be the essentialist way. There is another way to think of feedback, of the controller (e.x. the negative loop) and of the controlled system (e.x. a real circuit) functioning in terms of subjectivation. The controller is subjected, it has its control values set by human agency, and it is through the working of machines that it becomes subjectivized through the process by fixing the presupposed value. But as we saw in this case-study, it cannot regulate nor control social differences, e.x. the difference of skills of workers that is analogous to their training, while as we saw it has also a limited surveillance over physical differences. It is in this way that the human and the non-human, actors and actants, may be treated in a symmetrical and relative way, without having to turn to essentialist categories: as participants in the expanded production and reproduction of the total social capital.

In returning now to the question of defining intelligent control through what human intelligence is supposed to be, we cannot accept unquestionably human intelligence. In relating human and machine, Katherine Hayles writes that 'if meaning is constituted through relation, then juxtaposing men and machines goes beyond bringing two preexisting objects into harmonious relation. Rather, the analogical relation constitutes both terms through the process of articulating their relationship' [Hayles, 1999: 92]. Moreover we cannot hold to the human concept. It too has to be contemplated in historically emerging relations, power relations, which as I intended to have shown in this case-study are above all relations of production, relations constituted within production processes and under the hegemony of historically specific modes of production, here the capitalist mode of production.

In contemporary science and engineering, terms and names do not remain without consideration, although as the following extract might illuminate they are always caught up in power relations. In closing this thesis I quote the chairman of the meeting *'DEFINING INTELLIGENT CONTROL',* Panos Antsaklis, who drew the participants' attention to the effectivity of naming and the importance of the use (and misuse) of terms, only to conclude that not much attention should be given to it and instead they should concern themselves with meeting societal control needs. "Certainly the term intelligent control has been abused and misused in recent years by some, and this is of course unfortunate. Note however that this is not the first time, nor the last that terminology is used to serve one's purpose. Intelligent control is certainly a catchy term and it is used (and misused) with the same or greater abundance by some, as for example the term optimal has been used (or misused) by others; of course some of the most serious offenses involve the word "democracy"! For better or worse, the term intelligent control is used by many. An alternative term is "autonomous (intelligent) control". It emphasizes the fact that an intelligent controller typically aims to attain higher degrees of autonomy in accomplishing and even setting control goals, rather than stressing *the (intelligent) methodology* that achieves those goals; Autonomous control is also discussed in sections 2 and 3. On the other hand, "intelligent control" is only a name that appears to be useful today. In the same way the "modern control" of the 60's has now become "conventional (or traditional) control", as it has become part of the mainstream, what is called intelligent control today may be called just "control" in the not so distant future. What is more important than the terminology used are the concepts and the methodology, and whether or not the control area and intelligent control will be able to meet the ever increasing control needs of our technological society. This is the true challenge." [Antsaklis et al., 1993: 4; my emphasis]

In a present time in which the impacts of an economic neo-liberalism have reached to affect our European everyday lives, and the dogma of the self-regulation of the market has been radically challenged both by the emergence of a global-wide financial crisis and by the solution provided by major state interventions (and not Keynesian in form), from within the community and under the auspices of the methodological openness and variety of STS standing for Society, Science and Technology, and not just Science and Technology Studies, we may be allowed to question in a critical manner our multilateral historical past in order to shed light into questions concerning our contingent and uncertain future(s).

Athens, 2nd of October 2008.

F.T.

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