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GAS TURBINE POWERHOUSE

THE DEVELOPMENT OF THE POWER GENERATION GAS TURBINE AT BBC – ABB – ALSTOM

2ND EDITION

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Foreword

Gas turbines have become one of the most important engine types for electric power generation on a global scale – either as simple cycle installations or to a rapidly increasing extent as part of combined cycle power plants. This development is the result of many inherent advantages of this technique in comparison to alternatives – not the least its superiority in the category of cost of electricity.

During more than a century engineers of the Swiss development centre of A.-G. BBC Brown Boveri & Cie., from 1988 onwards ABB Asea Brown Boveri Ltd. and since 2000 Alstom Power Ltd. in Baden, Switzerland have significantly contributed to the achievement of today's advanced gas turbine concept and its successful integration in combined cycle applications. The present book provides a comprehensive and detailed insight on both technical and business aspects of the long-term genesis of this unique high technology product. This rather rare description of the development history of a thermal turbomachine puts also special attention on the human touch – a characterisation of leading engineering personalities of the time and the corresponding teamwork; triumphs and drawbacks accompany this fascinating professional account over decades – from a Swiss company nucleus of less than thousand to a global industrial company with several ten-thousands of employees. Numerous historical 'firsts' in gas turbine technology for power generation are highlighted – as summarized in Section 7.1 – ranging from the first realisation of the industrial, heavy-duty gas turbine in the 1930s to today's high technology gas turbine products, which combine excellent performance, extraordinary low environmental impact with commercial attractiveness.

Twenty years after Ernst Jenny's commendable book on 'The BBC Turbocharger' follows now the 'Gas Turbine Powerhouse' with a comprehensive description of gas turbine developments for power generation at BBC–ABB–Alstom. The book outlines not only the corresponding activities in gas turbine design and related disciplines, but covers also the historic development milestones of the major components – axial compressor, combustor, turbine and turbine cooling; the latter area with surprising, so far unknown revelations. The author Dietrich Eckardt provides a rather rare combination of technical and historic-economic insight, using engineering experiences of more than 40 professional years in turbomachinery research and gas turbine development, both for aero and power generation applications. The inclusion and thorough assessment of a broad variety of new sources and archive materials unveiled many interesting details of the gas turbine history, not the least surprising connections during the early parallel development of industrial and aero gas turbines.

On Friday 7 July 1939, 10.10 h started at Baden, Switzerland the full load certification test of the first power generation gas turbine for the utility plant at Neuchâtel, Switzerland – the first step of what has become a global success story and as such, a well-documented cause to celebrate this key event 75 years ago. This plant remained in service for 62 years – not bad for the first such order ever. The book provides the details to understand this engineering 'miracle', at best for the pride of present and the encouragement of future generations of engineers in this fascinating field of advanced technologies.

Baden, June 2013

Juerg Schmidli

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The writing of history, historiography,
is the 'doing of history', and engineers
should make sure that the historiography
of engineering is not left entirely to historians.
Recognition of this activity by the profession is very important.[1]

1 Introduction

This book tells the story of the power generation gas turbine (GT) from the perspective of one of the leading companies in the field over a period of more than 100 years and written by an engineer. With a global economic crisis imminent – triggered and accompanied by virtual stock market bonanzas and a few years after the illusions of a 'new economy' visibly failed – the time has come to reflect on real economic values based on engineering ingenuity and enduring management of technological leadership. For more than 120 years, engineers of the Swiss development centre of A.-G. Brown Boveri & Cie., ABB Asea Brown Boveri Ltd. from 1988 and Alstom Power Ltd. in Baden, Switzerland (CH) since 2000 have significantly contributed to the art of thermal turbomachinery design in general.

In the history of energy conversion, the gas turbine is relatively new. The first utility gas turbine to generate electricity at Neuchâtel[2], Switzerland ran at full power at Baden, CH on 7 July 1939[3] and was developed by Brown Boveri. The scope of this book starts somewhat earlier to explain influencing ideas and consequently foregoing developments contributing to this invention. It then describes the steady and impressive engine growth from the first local 4 MW emergency power unit until present-day advanced configurations that generate power for large metropolitan areas with unit sizes above 300 MW. This was no success story throughout, especially not in view of the actual business fortunes achieved. There were changes in the company affiliations of the various branches, changes in product portfolio and also some development dead ends. But a few of the original BBC product lines managed to stay in the frontline of advanced superior technology even from present global perspective.

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1 Presumably, this quotation has several fathers; the author, Werner Albring, put his encouragement in these thoughts, see also Footnote 7 for the whole context.

2 Neuchâtel is the capital of the equally named Swiss canton in the French-speaking part of Switzerland, some 150 km south-west of Baden. The city of 30,000+ inhabitants is sometimes referred to by the German name Neuenburg, since it originally belonged to the Holy Roman Empire, and later Prussia ruled the area until 1848.

3 Interestingly, the first gas turbine flight also took place in 1939 – only 51 days later. A Heinkel He 178 aircraft, jet-powered by a HeS3B engine of (only) 600 kN thrust, developed by Hans-Joachim Pabst von Ohain (1911–1988) took off on Sunday, 27 August from Rostock-Marienehe, D. In England, the 1930's invention and development of the aircraft gas turbine by the British Royal Air Force (RAF) engineer officer Sir Frank Whittle (1907–1996) resulted in a similar British flight in 1941. As will be outlined in a separate documentation, BBC was indirectly involved in both sides' developments of jet engines with advanced all-axial engine configurations, as they contributed their superior compressor design know-how.

In the meantime, the sheer duration of certain engineering developments over several decades allows interesting historic observations and deductions on inherent business mechanisms, the effects of technology preparations and organisational consequences. A look into the past bears revelations on the impact of far-reaching business decisions. The positive influence of strong, courageous and visionary personalities becomes visible to the same extent as the negative consequences of hesitation and idle waiting. These prospects of an in-depth review of its own historic background have led a number of companies to launch similar assessments. BBC started from a modest nucleus to become one of the largest engineering companies worldwide with operations in around 100 countries. In 1990, it had more than 220,000 employees under the label of ABB. The engineering conglomerate was and still is amazingly innovative and successful in a broad variety of engineering product ranges: DC and AC (direct and alternating current) motors, turbo-, diesel and water generators, transformers, high-voltage transmission and grid equipment, switches and relays, steam turbines for power and ship propulsion including related gearboxes, steam-generating Velox boilers and power generation gas turbines, electric and gas turbine drives up to and including complete railway and streetcar systems, turbocompressors for the iron and steel industry, but also for aero engine applications, turbochargers, wind turbines, electro boilers and furnaces, nuclear power plant equipment, high-frequency radio and telecommunication equipment, liquid-crystal displays, vacuum tubes and semiconductors, power plant controls – to name just the most important. These product ranges comprise development activities as well as manufacturing and service operations in general.

Only one of these areas found comprehensive documentation in a stand-alone book so far: The BBC Turbocharger[4]. In 2002 an ASME paper[5] with a review of 'ABB/BBC Historical Firsts' in advanced gas turbine technology got some attention. It was then indeed Ernst Jenny, the author of the successful turbocharger book who became a strong proponent of the idea to write a follow-on history of gas turbine development[6]. Industry history, especially that of Germany and Switzerland in the context of the 2nd World War, received the special attention of professional young historians in recent years. We owe them many fundamental clarifications and also sometimes rare technical 'golden nuggets' as a result of their unrelenting, in-depth ploughing through archive materials. When it comes to the technical interpretation of their findings, pure historians sometimes reach their limits, however. In line with this thinking Werner Albring[7], the 'nestor' of German fluid mechanics at TU Dresden for years provided strong encouragement to this project.

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4 See Jenny, The BBC Turbocharger

5 See Eckardt and Rufli, ABB/BBC Historical Firsts

6 Actually, the launching date of this book project can be exactly reconstructed. We met the late Ernst Jenny on 5 April, 2003 on the occasion of Georg Gyarmathy's 70th birthday (who passed away too soon on 24 October, 2009 at the age of 77). Gyarmathy, himself a former BBC director and successor to Traupel's chair for Fluid Machinery at ETH Zurich (1983–1998), was interested in technical history where he especially promoted the role of his Hungarian fellow countryman, the inventor G. Jendrassik, who built a small all-axial gas turbine and made early suggestions to apply the gas turbine for aero propulsion.

7 Prof. Dr. Werner Albring (1914–2007), was head of the Institute of Applied Fluid Mechanics at TU Dresden from 1952 until 1979 and author of one of the most intelligible textbooks on fluid mechanics. After his retirement he wrote several outstanding papers on the history of engineering and science (Helmholtz, Hagen, etc.) and in this context is known for his credo that qualified engineers should return to a responsible leadership role in view of the complex environment in industry and society, http://www.albring.info/

In fact, this is not the first approach to the subject. Our files contain a collection of material for a 'Swiss History of the Turbomachinery Industry' which was obviously planned in 1978/79, but the idea was dropped with the disruption of the BST industrial venture[8] at that time.

As had already been reported in the addressed ASME paper[5], one of the most intriguing aspects of the early BBC gas turbine history is the frequent in-depth involvement in parallel aero engine developments. Correspondingly, astonishing findings were made in the meantime as a consequence of further investigations and they would disrupt in full breadth the general scope of this stationary GT company history. A full roll-out has to wait for a follow-on publication.

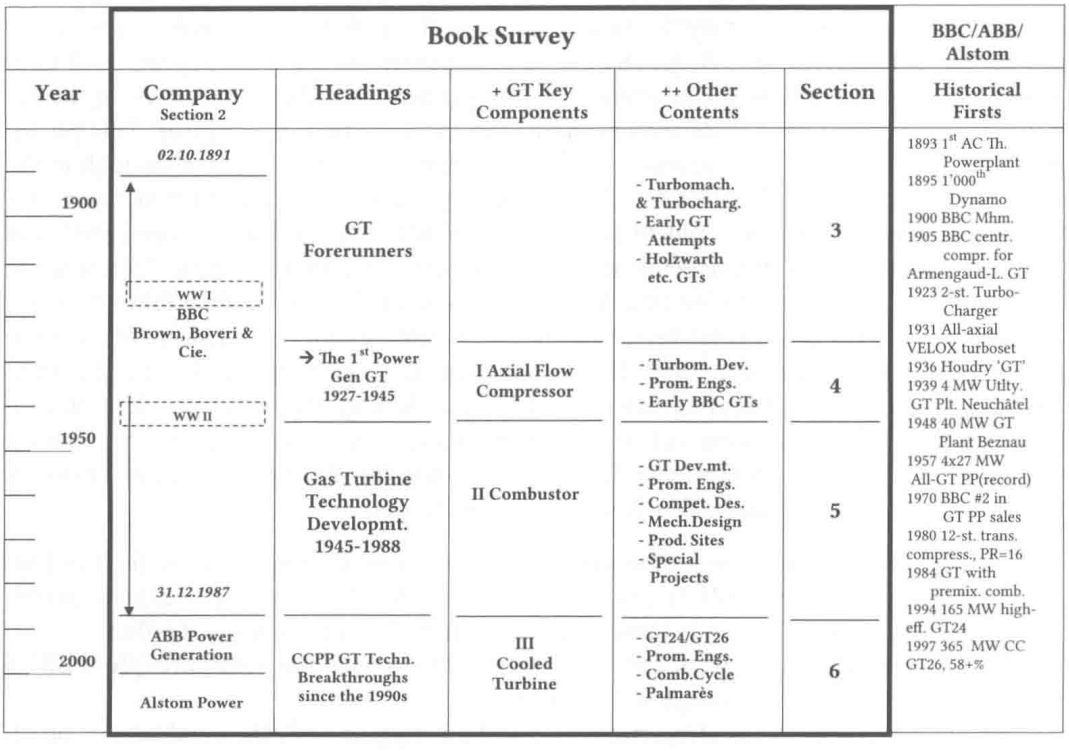

Figure 1-1 *Survey of the book structure*

Figure 1-1 illustrates the structure of this book in graphic form. The left-hand scale covers the period from the formation of BBC until today, with the various Company names shown

8 BST Brown Boveri-Sulzer Turbomaschinen AG was founded in 1969 as a joint venture between BBC Brown Boveri & Cie., Baden CH and Gebrüder Sulzer AG, Winterthur CH (after Sulzer had already decided to cooperate with Escher Wyss AG before) as part of a necessary concentration process to become more competitive e.g. with a common, standardized product portfolio (Section 5.1.3). The effort failed and BST was already resolved again on 1 July, 1974. It appears that the planning for a joint Swiss turbomachinery history was a relict of foregoing BST times. Existing materials and correspondence – see BBC, Geschichte des Schweizer. Turbomaschinenbaus, 1982 – between 07/1978 and 09/1979 foresaw BBC contributions from Cl. Seippel, L.S. Dzung and H. Pfenninger, but the parties obviously agreed to stop the effort after Prof. W. Traupel's excuse that the 3rd edition of his own book had higher priority.

over time in the next column. The history of this succession of companies from BBC Brown, Boveri & Cie. via ABB Power Generation Ltd. to the present ALSTOM will be told in Section 2. Sections 3 to 6 in principle follow the chronology, with a few exceptions. Section 3 outlines in short the centuries of collecting experience in turbomachinery, a description that normally starts with the introduction of the reaction principle by Heron of Alexandria. I tried not to follow the trodden path and looked for some lesser known examples with reference to the gas turbine and the Swiss location.

Edward Constant[9], the author of one of the most comprehensive and well-researched books on GT history, differentiates between a first, aborted gas turbine revolution (1900-1920, Stolze, Armengaud) and a second, successful attempt, mainly led by BBC in the 1930s.

I have maintained this structure in Section 3, where all 'early attempts with the GT principle' belong to the first category. Section 4 describes the path to the 1st power generation gas turbine at Brown Boveri, Baden, Switzerland in the timeframe from approx. 1927 until 1945. Besides a description of the actual development activities, the text focuses on the decisive component for the GT development success: the axial flow compressor. This principle of a combined chronological and subject-oriented order has been carried through in the following sections. In Section 5, the GT's 'middle component' – the combustion chamber – has been linked to the development period for the BBC gas turbines between 1945 and 1988, the end of BBC as an independent, stand-alone company after 97 years. The narration about the 3rd GT component along the flow path – the cooled turbine – then follows in Section 6 in the context of the most recent technology breakthrough – the success of the combined-cycle power plants after 1990. This presentation has a certain benefit, since the individual GT component histories are kept together, letting the inherent development rationale become more transparent. Moreover, with a few exceptions, like e.g. the first introduction of a transonic compressor design in the 1980s, this deliberately chosen structure fits the development highlights touched on surprisingly well:

- The successful realisation of the axial compressor was *the* precondition for the BBC success towards the 1st utility gas turbine in the 1930s. Vice versa, the lack of an efficient compressor unit was in most of the foregoing efforts the reason of failure.
- The intermediate phase from 1945–1988 saw at its backend the breakthrough of BBC's unique low-emission combustion technology.
- Finally, the highly demanding, integrated turbine designs with the combination of advanced aerothermodynamics and sophisticated production technology only materialised after 1990; but they also triggered reflections on the recently rediscovered, early beginnings of BBC's turbine blade cooling technology in the 1930s.

Besides this repetitive link of section headings/contents and the 3 key GT components in the core Sections 4 to 6, each of these chapters with varying emphasis contains a treatise of

- the developments during that period,
- the relevant organisational changes,
- the most prominent, dominant engineering personalities,
- the relevant market observations and – where applicable
- the competitive developments.

9 See Constant, The Origins of the Turbojet Revolution

In a short final Section 7 'Les Palmarès', the historical 'firsts' in power generation technology by BBC/ABB and Alstom are listed in chronological order, together with a list of the responsible GT Development Directors in Baden, CH during the covered period of nearly 90 years and of the dedicated members of the GT Development 'Hall of Fame' which since 1995 is awarded annually for individual, outstanding contributions to the gas turbine development activities.

This book is written to be read from start to finish as a continuous story, once in a while interspersed by summarising description and analysis. Details and lengthier excursions have been shifted to the Footnotes on the same page, where the patient reader may find a few 'nuggets'. I hope that the interaction of the various elements of the story as described above will not confuse but rather enlighten the readers together with the presumed advantages as the narrative proceeds. References to the used literature have been collected in the comprehensive Section 8 'Bibliography'.

On the other hand, anyone who prefers to use the book as a kind of reference is recommended to turn to the Index listings – of Names, Section 9 and of Subjects, Section 10. Section 11 shall assist understanding with a comprehensive list of used 'Nomenclature and Abbreviations', followed finally by Section 12 – a short portrait of 'The Author'.

At the end of these introductory remarks, special thanks go to Juerg Schmidli and Peter Rufli from Alstom Power, Gas Turbine Development in Baden, Switzerland for defining frame and pace of this project in a generous manner. This work was considerably facilitated by a thorough preparation of the relevant, notwithstanding huge literature body for this task. The Alstom-internal database 'GT History References' in the meantime covers nearly 1'200 objects (papers, journal articles, books) that have been collected, digitised and put into a searchable form by Robert Marmilic, who herewith prepared the reliable foundation of this project. The numeration of this database is also given in the attached Bibliography in brackets [...], as an extra-benefit for Alstom-internal readers. Several colleagues contributed extensively from their own broad development experiences and by carrying out a careful proof reading of the manuscript. Mrs. Joanna Stone helped to smooth the English text and so considerably alleviated the 'readability' of engineering explanations; the endeavour to produce English technical diction was followed in the tradition of former, internationally established house publications such as 'Brown Boveri Review'. Special thanks are owed to Claude Seippel's son Olivier (1926–2012), also employed in various functions at BBC, who helped to revive personal memories of his father, especially by providing insight into the BBC part of Cl. Seippel's diary notes.

Invaluably, the great resources of the ABB Historic Archive, Baden-Daettwil, CH (Docuteam Tobias Wildi, Mrs. Raffaela Luetolf and Norbert Lang) and of the ABB ZX Test Dept. Archive (Bernhard Schoenung, Hueseyin Coskun) have been made available for these studies – with thanks to ABB HR Management (Renato Merz, Volker Stephan). Mrs. Cornelia Bodmer maintained contact to the ETHZ Library, squeezing rare information sources out of NEBIS[10]. What could not be made available in Switzerland was still in reach of the ever-ready specialists of the MTU Aero Engines, Information Services team in Munich, Germany (Helmut Schubert, Reinhard Glander, Mrs. Sabine Hechtl), in the meantime probably the

[10] ETHZ on-line catalogue: NEtzwerk von Bibliotheken und Informationsstellen in der Schweiz (Swiss libraries network).

best-assorted library for gas turbine and turbomachinery issues in Europe. The powerhouse graphic[11] on the book cover is by, and courtesy of Mark Welsh, Jersey City, NJ, USA. Finally, the author wants to thank a number of present and former colleagues for significant help; they spent considerable time and energy digging deeply into their memories, archives and files to reconstruct the past in as much detail and colour as possible: Jan-Erik Bertilsson, Franz Farkas, Fredy Haeusermann, Jaan Hellat, Wolfgang Keppel, Hanns-Juergen Lichtfuss, Uwe Schmidt-Eisenlohr, Martin Schnieder and Konrad Vogeler.

No one can be an expert on such a long period and on so many different technical subjects as addressed in this book. Notwithstanding, the broad external support and a thorough study of the available sources, deficits and drawbacks in the presentation of the comprehensive materials cannot be ruled out. The overall responsibility for this book, the selection of contents and the picking of individual aspects, technically and otherwise, its pros and cons, inherent correctness and hopefully not too many flaws remains with the author – and his necessarily subjective view on this fascinating profession. Clearly believing in the 'wisdom of the many' I look forward to receiving comments and proposals for improvements. In this respect the book may find many generous readers who enjoy the intended broad, nevertheless concise approach to nearly one hundred years of unique, technical company history.

Baden / Munich, October 2013

Remarks to the second edition:

The feedback to the first edition with 1'900 printed copies was very positive; only half a year later an improved second edition appears herewith, thanks to many supplementary technical suggestions and corrections from former colleagues and helpful hints of careful readers; contents and structure of the book are unchanged. It is worthwhile to note that quotations are provided in original form, so that misspellings, uncommon unit designations, etc. are kept.

Lenzerheide / Munich, April 2014

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[11] © Mark Welsh. The illustration stands here to visualise **the** powerhouse in generic form; actually, it represents the Hudson & Manhattan Railroad Powerhouse designed as a 'technical cathedral' by John Oakman and erected 1906–08, at the time of first gas turbine trials and 30 years in advance of the first practical introduction of GT power generation. http://jclandmarks.org/campaign-powerhouse.shtml