# Preface

The PID controller is the most common solution to practical control problems. Although controllers with proportional and integral action have been used from the time when windmills and steam engines were the dominant technologies, the current form of the PID controller emerged with the pneumatic controllers in the 1930s. The controllers have been implemented in many different ways using mechanical, pneumatic, electronic, and computer technology. The development accelerated when the microprocessor implementations appeared in the 1980s. One reason was that the computer implementations made it possible to add features like auto-tuning and diagnostics, which are very beneficial for users. From an engineering perspective, it is particularly interesting to analyze what happened at the technology shifts, when some important features were rediscovered and others were added.

This book has grown out of more than 25 years of development of auto-tuners for PID controllers in close collaboration with industry. Through this work, we have been exposed to a large number of real industrial control problems. We have benefited much from participating in development, commissioning, and troubleshooting of industrial controllers. The practical work has also inspired research.

This book is the last part of a trilogy. The first book, *Automatic Tuning of PID Controllers, 1988*, which had 6 chapters, gave a short description of our early experiences with development of relay auto-tuners. The second book, *PID Controllers: Theory, Design, and Tuning, 1995*, which has 7 chapters, grew out of the need for a broader coverage of many aspects of PID control. In particular, it reviews many design methods for PID controllers that we investigated in connection with our work on auto-tuners.

The knowledge about PID control in 1995 still was not satisfactory for design of auto-tuners. One drawback was that the user had to provide the controller with design choices. It is particularly difficult for a user to assess if dynamics is dead-time or lag dominated. This question stimulated further research. Because of the drastic increase in computing power, it was also possible to use design algorithms that require more computations.

Tuning and design of PID controllers have traditionally been based on special techniques. Robust control was a major development of control theory that matured in the late 1990s, resulting in powerful design methods based on robust loop shaping. This stimulated us to initiate a research program to adapt these methods to PID control. At the same time, it seemed natural to bring PID control closer to the mainstream ideas in control. When working with industrial auto-tuners, we also saw a great need to include diagnostics in the controller, because it is no use to tune a controller if the process has severe malfunctions. The present book, *Advanced PID Control*, is the result of this effort.

With a total of 13 chapters, this new book substantially expands on some of the topics covered in the previous versions and provides several new chapters that deal with controller design, feedforward design, replacement of the Ziegler-Nichols tuning rules, predictive control, loop and performance assessment, and interaction. At this point in our book trilogy, we assume that the reader is highly familiar with control theory.

Our research has given a deeper understanding of the trade-offs between load disturbance attenuation, injection of measurement noise, and set-point response. We have also been able to answer questions like: Should a controller be tuned for response to load disturbances or set points? What information is required to design a PID controller? When can derivative action give significant improvements? When are more complicated controllers justified? When is it justified to develop more accurate process models? With the knowledge developed, it is now possible to design auto-tuners that can make these assessments autonomously. In addition, we have developed new simple methods for designing PID controllers.

As an example of the insight gained we can mention that control theory tells that it is not necessary to make a compromise between tuning for load disturbance response and set-point response. Both requirements can be satisfied by using a controller with two degrees of freedom, which combines feedback and feedforward. The feedback gains should be chosen to satisfy requirements on disturbance attenuation and robustness. The desired response to set-point changes can then be obtained by proper use of feedforward. Set-point weighting is a simple form of feedforward for PID control. In some cases, it is justified to use more elaborate feedforward. For this reason, we have included a chapter on controller design and another chapter on feedforward in the new book.

The robustness analysis also shows the advantage of having low controller gain at high frequency, high frequency roll-off. This can be accomplished by filtering the process output by a second order filter. Based on the insight obtained, we recommend extended use of set-point weighting or more advanced feedforward. We also recommend that the process output is filtered using a second order filter.

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