INSTRUMENT ENGINEERS' HANDBOOK

Third Edition

Process Software and Digital Networks

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CRC PRESS

ISA–The Instrumentation, Systems, and Automation Society

PREFACE

THE MATURING OF THE I&C PROFESSION

The first volume of the *Instrument Engineers' Handbook* (*IEH*) described the devices and methods used in performing automatic industrial process measurement and analysis. The second volume of the *IEH* dealt with automatic process control devices and systems used in our various industries. This third volume of the *IEH* provides an in-depth, state-of-the-art review of all the existing and evolving digital communication and control systems. Although the transportation of digital information by buses and networks is a major topic in this volume, the total coverage of the volume includes much more. This volume also describes a variety of process control software packages, which are used in plant optimization, maintenance, and safety-related applications. A full chapter is assigned to plant design and updating, while safety and operations-related logic systems and the design of integrated workstations and control centers are also emphasized. The volume concludes with a substantial appendix, providing such practical information as bidders' lists and addresses, steam tables, materials selection for corrosive services, and much more.

It is hoped that the publication of this third volume of the *IEH* will contribute to increasing the safety and efficiency of all control systems. Although in the previous editions of the *IEH* we have advocated the use of intelligent self-monitoring and self-diagnosing instrumentation, now it seems that the time has come to take the next step and aim for unattended and self-optimizing industrial control systems. It is time to proceed from the level of self-monitoring and self-diagnosing packages to self-healing systems requiring a minimum of maintenance.

Ours is a relatively young profession. I do hope that this third volume of the *IEH* will also improve the respectability and professional standing of the instrumentation and control (I&C) profession, which is still evolving. Yet, if we compare the professional standing and the self-image of instrumentation and control engineers to those of, for example, mechanical or chemical engineers, we find ourselves at a disadvantage.

The list of disadvantages starts at the universities, which offer ME or ChE degrees, but not too many of them offer degrees in I&C engineering. Some do not even have an I&C department. Even those that do often tend to treat control as if it were a subfield of mathematics. At such universities control issues are often discussed in the "frequency domain," and control problems are analyzed by using partial differential equations and Laplace transfer functions. Under such conditions, the engineering students, when first exposed to the field of process control, often receive the wrong impression of what the I&C profession is all about.

Our engineering societies could also do a better job to improve our professional image. The main goal of such engineering societies as ASME or AIChE is to serve the professional development of their members. These societies focus on preparing scientific publications, on generating high-quality engineering standards, or on organizing courses aimed at assisting the professional advancement of their members. In contrast to that, the leadership of some I&C societies is dominated not by the users, but by the manufacturers, and focuses not on the professional advancement of their members, but on serving the commercial interests of the vendors.

The differences between the professional standings of I&C and other engineering disciplines are also visible in most operating plants, where one has no difficulty in finding a resident ME or ChE, but when one asks for the resident I&C engineer, the answer often is, "We have only instrument maintenance technicians, the vendors take care of our instrument engineering." This shows an elementary lack of understanding of the most basic requirement of good control. It is that **in order to properly control a process, one must fully understand its unique personality, and vendors can seldom, if ever, do that**.

Another observable difference is demonstrated by the bookshelves of the members of the different engineering disciplines. If one walks into the office of an ME, it is likely that one will see one or more editions of *Marks' Handbook* on the bookshelf. The same holds true for the offices of ChEs, except that there it will be *Perry's Handbook* on the bookshelves. In contrast, the bookshelves of most I&C engineers are likely to be flooded by vendors' catalogs but few professional handbooks are likely to be seen there.

FRIDAY'S NOTES

Having painted this rather dark picture, I should bring the topic of our professional standing into its proper perspective. We all know that it takes time for an engineering profession to mature, and we also know that I&C is a very young profession. I will try to demonstrate the youth of our profession by using the example of my handbook.

In 1962, at the age of 26, I became the Chief Instrument Engineer at Crawford & Russell, an engineering design firm specializing in the building of plastics plants. C&R was growing and my department also had to grow. Yet, at the age of 26 I did not dare to hire experienced people, because I did not think that I could lead and supervise older engineers. Yet the department had to grow, so I hired fresh graduates from the best engineering colleges in the country. I picked the smartest graduates and, having done so, I obtained permission from the C&R president, Sam Russell, to spend every Friday afternoon teaching them.

In a few years my department had not only some outstanding process control engineers, but C&R also saved a lot on their salaries. By the time I reached 30, I felt secure enough to stop disguising my youth. I shaved off my beard and threw away my thick-rimmed, phony eyeglasses. I no longer felt that I had to look older, but all the same, my Friday's notes still occupied a 2-ft-tall pile on the corner of my desk.

In the mid-1960s an old-fashioned Dutch gentleman named Nick Groonevelt visited my office and asked: "What are all those notes?" When I told him, he asked: "Does your profession have a handbook?" I answered with my own question: "If it did, would I be teaching from these notes?" (Actually, I was wrong in giving that answer, because Behar's *Handbook of Measurement and Control* was already available, but I did not know about it.) "So, let me publish your notes and then the instrument engineers will have a handbook," Nick proposed, and in 1968 the first edition of the *Instrument Engineers' Handbook* was published.

In 1968, the Soviet tanks, which I fought in 1956, were besieging Prague, so I decided to dedicate the three volumes of the *IEH* to the Hungarian and Czech freedom-fighters. A fellow Hungarian–American, Edward Teller, wrote the preface to the first edition, and Frank Ryan, the editor of *ISA Journal*, wrote the introduction. My co-authors included such names as Hans Baumann, Stu Jackson, Orval Lovett, Charles Mamzic, Howard Roberts, Greg Shinskey, and Ted Williams. It was an honor to work with such a team. In 1973, because of the great success of the *IEH*, I was elected to become the youngest ISA fellow ever. But the fact still remains that ours is a very young profession: when the *IEH* came out, Marks' and Perry's handbooks were in their fifth or sixth editions!

PROGRESS

The third edition of the *IEH* was initially planned for three volumes. They were to cover the subjects of process measurement, process control, and process software. Chilton published the first two volumes in 1995. The publishing process was then interrupted when Walt Disney acquired Chilton in 1996. I could do nothing but wait for work on the series to resume. In October 2000, CRC Press obtained the rights to publish the third volume.

This delay, though unfortunate, also had some positive consequences. First, CRC agreed with ISA to market the *IEH* jointly. Second, the onset of the age of digital communications made it possible for me to find the best experts in the world for every key topic in this volume. This was an important consideration because the three volumes of the *IEH* explore nearly 1000 diverse topics from anenometers to weirs and from controlling airhandlers to controlling wastewater treatment processes. Finding the best authors possible in an efficient manner would have been next to impossible before the Internet.

Now, as I start to invite co-authors for the fourth edition of this handbook, the Internet continues to be an invaluable research and communication tool. By the click of a button (liptakbela@aol.com) experts residing anywhere in the world can also contact me and offer to contribute to the IEH, thus sharing their knowledge, accumulated over a lifetime, with the international community of I&C professionals.

THE FUTURE

When Yale University invited me to teach I&C, I did not like it that my course was being offered by its chemical engineering department, because Yale did not have an independent I&C department. On the other hand, I was pleased that I was allowed to discuss control theory in the "time domain." Therefore, I used no mathematical abstractions, partial differential equations, or Laplace transfer functions. Instead, I talked about easily understandable terms like transportation lags and capacities, dead times, and time constants. In short, the course I gave was down to earth and practical. It was based on my old "Friday's notes." So, while teaching I&C in a ChE department was unfortunate, teaching I&C in the time domain, and not in the frequency domain, was a step forward.

In working with the publishers of the *IEH* over the past decades, I was also reminded of the unrecognized nature of the I&C profession. Between the various editions, I have seen the *IEH* promoted in the categories of chemical engineering, electrical engineering, and computer engineering books, but seldom in its own category. This, too, has bothered me. It just seems to be taking too long to recognize that I&C is a separate and distinct profession. When CRC agreed to a joint publication with ISA, this was a small but significant step toward gaining full recognition for our slowly maturing I&C profession.

In general, it is high time for our universities and publishers to recognize the existence of instrument engineering as a distinct and respectable profession. It is time for industrial management to understand that the availability of in-house instrument engineering know-how is essential. It is time for instrument societies to focus less on the advertising dollars from the vendors and more on helping the users by providing education and standardization. It is hoped that in the long run these steps will help in gaining the deserved respect for our slowly maturing I&C profession.

DIGITAL SYSTEMS

In the past, we first standardized on the pneumatic signal range of 3 to 15 PSIG and later on the electronic transmission and control signal range of 4–20 mA DC. As we move from the analog to the digital age, we also need a uniform worldwide standard for digital signals, which is universal. We need a fully open network, one that is *not* based on any particular vendor's standard. Yet today, there exist some 30 digital protocols, which all call themselves fieldbuses. What the International Electrotechnical Commission (IEC) did was not to issue a single standard, but simply to take the conglomeration of eight of these disparate, proprietary, non-interoperable vendors' standards and combine them into a single document (IEC 61158). This is intolerable! This is like expecting to run a plant from a control center in which eight operators might speak eight different languages.

While some progress has been made in providing an Open System Interconnect (OSI) model and while most vendors support Ethernet-TCP/IP (transmission control protocol/Internet protocol) connectivity at the business interface level, much remains to be done. With the passage of time, interoperability among the field device network front runners (Foundation Fieldbus, HART, and PROFIBUS-PA/DP) has also improved, but (because of the war for the dominance at the field level of the application layer) interoperability still remains a marketing term of blurred meaning. This is more than undesirable! This is unsafe! **The responsibility of the I&C engineering societies and of this handbook of mine is nothing less, but to work for a truly open and universal digital network standard.**

Greg Shinsky was right when he warned that smart controllers alone cannot solve the problem of dumb users. No, the problem of dumb users can only be solved by education and by placing the interests of the profession ahead of those of individual manufacturers. To achieve that goal, both the various I&C engineering societies (including ISA) and our publications, such as my handbook, have important roles to play. If we all pitch in, we can improve not only the next edition of the *IEH* and the professional atmosphere at ISA, but we can also increase the respectability and maturity of the instrument engineering profession as a whole.

CONTROL OF NON-INDUSTRIAL PROCESSES

A few years ago a group of social scientists invited me to Harvard University to talk about the control of non-industrial processes. I started the lecture by listing the information that we need about any process, before we can start designing a system to control it. Among the information needed, I mentioned the set point and the manipulated variable (the control valve), which we must have to build a control loop. As an example, I mentioned that, if we wanted to build a control loop, which would control the population of our planet, we would have to agree on both a "set point" and a "manipulated variable" for it. I am not saying that it is necessarily up to us humans to control the population of the world. What I am saying is that we have not even agreed on the desired set point or on the manipulated variable for such a loop!

Someone from the audience interrupted me at this point and asked about the control modes for such a population controller. "Should the controller be proportional and integral (as in the case of level control) or proportional and derivative (as in the case of batch neutralization)?" he asked. "One should only start thinking about control modes when the loop itself exists, not before," I responded. Therefore, humankind will first have to decide if there is a maximum limit to the total population of our planet (set point). Once there is general agreement on that, we will have to agree on the manipulated variables (on the means to be utilized to keep the population below that limit). Reaching such agreements will not be easy because the derivative settings of our political institutions (anticipation into the future) are very short (usually only 4 years) and because there is no past precedent in our culture for making decisions of such magnitude.

Controlling Evolution

It is difficult for us to be concerned about events that are likely to occur after we are dead. It is difficult, because human evolution in the past has been under the control of nature and it is hard for us to accept that we too are responsible for the future of the planet. I do not mean to suggest that we have "conquered nature" or that we are controlling our own evolution. No, that is not the case! The Creator has placed nature in the driver's seat of all evolutionary processes on this planet. Yet, He has permitted humans to change some of nature's conditions. For example, He allowed humans to minimize the discomforts caused by the weather and also allowed us to reduce the time it takes to travel, by using up some of the exhaustible resources of the planet.

Therefore, if humankind fails to come up with a set point and a manipulated variable for the population control loop, nature is likely to select and implement it for us. One can only hope that there is enough derivative (enough anticipation of future events) in our combined wisdom to prevent that from happening, because if we wait for nature to close the population control loop, the "throttling" will neither be smooth nor gradual. "So, in order to control population, we need to modify human attitudes, human culture?" asks a balding gentleman. "Yes, we can view the relationship between culture and population control as a cascade loop, where culture is the master controller which is herding a number of slave loops, one of them being population," I responded.

Controlling Cultural and Social Processes

Culture is a mostly dead-time process. It takes 10 to 20 years for a child to form his or her opinions and values. At the beginning of our individual lives, every child's mind is a blank page. Our moral and ethical standards are inscribed by our churches, our schools, by the media, and by the examples of our role models, most importantly by our parents. To understand culture as a controllable process, we must also realize that culture is the sum total of all the beliefs and convictions of all members of our society.

For a society to function smoothly, at least three generations should share the same moral and ethical values. When the prevailing culture changes faster, this can result in a difference between the moral standards of the generations. As a consequence of cultural conflicts between societies of different nations or among the generations of the same nation, "their manipulated variables will interact." These interactions can be desirable (elimination of prejudices, clarifying environmental interrelationships) or undesirable (materialism, selfishness, amoral or cynical attitudes). Whatever the nature of the changes, "de-coupling of the loops" is necessary, if society is to function smoothly and effectively. Therefore, the methods used in de-coupling the interacting control loops can also be used in controlling social or cultural processes.

Economic and Political Processes

De-coupling is also needed when the interests of various segments of society collide. As long as the de-coupling (conflict resolution) can be subordinated to the shared ethical and moral standards of society ("one nation under God," "all men are created equal," etc.), a hierarchical control system (multilayered cascade) will function properly. On the other hand, problems will arise if the set point (the moral standards of this shared cascade master) becomes fuzzy. Such fuzziness is occurring right now, because business is already "globalized" while the political, legal, educational, or other institutions are not. It is the fuzziness of this cascade master that allows perfectly moral and ethical individuals to purchase goods made by child labor in environmentally polluting plants. Such fuzziness could be eliminated by inserting a slave control loop (implemented by, say, a color-coded label on all imported goods).

I also talked about the importance of the degrees of freedom of the controlled process. The number of these degrees identifies the number of process variables that can be independently controlled (in case of a train—one, ship—two, etc.). If we try to control more variables than the number of degrees of freedom that the process has, the control loops will fight each other and the controlled process will become unstable. This discussion of degrees of freedom led to questions related to controlling such complex processes as the economy and the political system.

HERDING AND ENVELOPE CONTROLS

In multivariable processes one cannot use a single set point, but must implement either a "herding" or an "envelope" control configuration. When implementing herding control, all controlled variables are observed simultaneously and continuously, but correction is applied to only one variable at a time. The selected control variable is the one that is farthest away from where it should be. A herding loop does the same thing that a herding dog does when it is herding 1000 sheep by going after one sheep at a time (by manipulating only one variable at a time), the one that is farthest away from the desired overall goal or aim of the control system.

Envelope control is different. Here, an allowable gap (upper and lower limits) is assigned to each controlled variable. From the totality of these gaps, a multidimensional control envelope results. If all the controlled variables are inside this envelope, no corrective action is taken. If a controlled variable drifts to one of the boundaries of the envelope, a correction is initiated.

Envelope control is best suited for **controlling the economy**, because our overall economic well-being is a function of several variables of similar importance (unemployment, inflation, corporate profits, interest rates, budget deficits, etc.). In contrast, the herding control model is more suitable for political process, because in that process, one consideration is more important that all the others. This critical consideration is to guarantee that all votes have the same weight.

In **controlling the political process** all other variables should be subordinated to this one goal, and all variables should be herded in the direction of guaranteeing equal influence to all well-informed voters. In this sense, the one-party systems completely eliminate all degrees of freedom, while the two-party systems are superior, but still restrictive. This control analysis suggests that maximizing the degrees of freedom of the political process would also optimize it. If that conclusion is correct, then the public financing of the campaigns of all acceptable political candidates and the elimination of private contributions could be a step in the right direction.

NATIONALISM AND GLOBALIZATION

It was already noted that the "dead-time" of forming cultural attitudes and cultural loyalties can take decades. It is worth noting that our loyalty to "our culture" and to the traditions of our extended family (our nation) harms no one. It is a form of healthy loyalty, which should never be given up or exchanged. Yet, this loyalty should not stand in the way of developing other loyalties. A person with multiple loyalties is a richer and happier person.

If one can maintain one's 100% loyalty to one's own culture while simultaneously developing an understanding and respect for another, that person has become a richer individual, a 200% person. Understanding and accepting this will be the great test of the "globalization process." Globalization can aim for a multicultural and hence richer global society, but it can also result in a uniformly commercialized and hence poorer culture for all people. The choice is ours, but to control the globalization process, we must also understand its time constants, which in case of electronic commerce can be seconds, while in the cases of culture or ethical and moral standards can be decades or even centuries.

MATCHING OF TIME CONSTANTS

Similarly to the control of culture, the time constants of global biology and its relationship with the preservation of the species must also be understood. For example, it takes thousands of years to displace the waters in all the oceans only once. Therefore, the irreversible consequences of the pollutants that we are discharging into our receiving waters today might not fully evolve for a couple of millennia. The time constants of the processes involving atmospheric pollution and global warming are similarly long and just as poorly understood.

The time requirements of switching to nonpolluting and inexhaustible energy sources are also critical. We do not know which of the proposed inexhaustible processes will ultimately replace the fossil fuels as our new, long-term energy supply. We do not know which of a dozen proposals will eventually work. We do not know if solar energy, collected by artificial islands around the equator will fuel a hydrogen-based economy or we will "burn" the carbon dioxide in the air, use solar cells, wind turbines, or what. What we do know is that fossil fuels are exhaustible, that the disposal problems associated with nuclear waste are unsolved and that the time needed to develop an economy based on nonpolluting and inexhaustible energy sources is long. So the wisdom of process control would suggest that we had better get started!

We will only be able to adjust our actions to protect and serve the future generations when we fully understand the time constants of the cultural and physical processes of our planet. To do that, it is not only necessary to understand the basic principles of process control but it is also necessary to help the process control profession gain the kind of respect and maturity that it deserves.

The goal of the three volumes of the *Instrument Engineers' Handbook* is nothing less than that. I do hope that your verdict will be that the co-authors of these volumes have made an important contribution to increasing the respectability of the I&C profession.

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DEFINITIONS

AMPACITY The current (amperes) a conducting system can support without exceeding the temperature rating assigned to its configuration and application.

ATTENUATION Loss of communication signal strength.

BACKPLANE Physical connection between individual components and the data and power distribution buses inside a chassis.

BALUN Balanced/unbalanced. A device used for matching characteristics between a balanced and an unbalanced medium.

BANDWIDTH Data-carrying capacity, the range of frequencies available for signals. The term is also used to describe the rated throughput capacity of a given network medium or protocol.

BASEBAND A communication technique where only one carrier frequency is used to send one signal at a time. Ethernet is an example of a baseband network. Also called narrowband. Contrast to **broadband**.

BONDING The practice of creating safe, high-capacity, reliable electrical connectivity between associated metallic parts, machines, and other conductive equipment.

BROADBAND A communication technique that multiplexes multiple independent signals simultaneously, using several distinct carriers. A common term in the telecommunications industry to describe any channel with a bandwidth greater than a voice-grade channel (4 kHz). Also called wideband. Contrast to **baseband.**

CAPACITANCE The amount of charge, in coulombs, stored in a system necessary to raise the potential difference across it 1 V; represented by the SI unit farad.

DATA SERVERS A standard interface to provide data exchange between field devices and data clients.

DEMULTIPLEXING Separating of multiple input streams that were multiplexed into a common physical signal back into multiple output streams.

DEVICE DESCRIPTION A clear and unambiguous, structured text description that allows full utilization/operation of a field device by a host/master without any prior knowledge of the field device.

ETHERNET A baseband local area network specification developed by Xerox Corporation, Intel, and Digital Equipment Corporation to interconnect computer equipment using coaxial cable and transceivers.

FIELDBUS An all-digital, two-way, multidrop communications system for instruments and other plant automation equipment.

FIREWALL Router or access server, designated as a buffer between any public networks and a private network.

GROUND A conducting connection, whether intentional or accidental, between an electrical circuit or equipment and the earth, or to some conducting body that serves in place of earth. (See NFPA 70-100.)

GROUND FAULT PROTECTOR Device used to open ungrounded conductors when high currents, especially those due to line-to-ground fault currents, are encountered.

HOME RUN WIRING Wire between the cabinet where the fieldbus host or centralized control system resides and the first field junction box or device.

HUB (SHARED) Multiport repeater joining segments into a network.

C	coulombs
°C	Celsius degrees of temperature
ca.	*circa*: about, approximately
CAC	channel access code
CAD	computer-aided design
cal	calorie (gram, =4.184 J); also g-cal
CAN	control area network or control and automation network
CATV	community antenna television (cable)
CBM	condition-based maintenance
cc	cubic centimeter (=10^{-6} m^3)
CCF	common cause failure
ccm	cubic centimeter per minute
CCR	central control room
ccs	constant current source
CCS	computer control system
cd	candela, symbol for basic SI unit of luminous intensity
CD	compact disk, compel data, or collision detector
C^D	dangerous coverage factor
CDF	cumulative distribution function
CDMA	code division multiple access
CDPD	cellular digital packet data
CEMS	continuous emissions monitoring system
CENP	combustion engineering nuclear power
CFM or cfm	cubic foot per minute (28.32 lpm)
CF/yr	cubic foot per year
Ci	curie (=3.7×10^{10} Bq)
CI	cast iron
CIM	computer-integrated manufacturing
CIP	computer-aided production or control and information protocol (an application layer protocol supported by DeviceNet, ControlNet, and Ethernet/IP)
CLP	closed-loop potential factor
cm	centimeter (=0.01 m)
CM	condition monitoring
CMMS	computerized maintenance management system
CMPC	constrained multivariable predictive control
CMOS	complementary metal oxide semiconductor
cmph	cubic meter per hour
CNC	computerized numerical control
CNI	ControlNet International
CO	controller output
COM	component object model
COTS	commercial off-the-shelf
cos	cosine, trigonometric function
cp or c.p.	(1) candle power; (2) circular pitch; (3) center of pressure (cp and ctp may also be used for centipoises)
cpm	cycles per minute; counts per minute
cps	(1) cycles per second (=Hz); (2) counts per second; (3) centipoises (=0.001 Pa.s)
CPS	computerized procedure system
CPU	central processing unit
CRC	cyclical redundancy check or cyclic redundancy code (an error detection coding technique based upon modulo-2 division. Sometimes misused to refer to a block check sequence type of error detection coding)
CRLF	carriage return-line feed
CRT	cathode ray tube
CS	carbon steel
CSMA/CD	carrier sense, multiple access with collision detection
CSS	central supervisory station
cSt	centistoke
CSTR	continuous-stirred tank reactor
CTDMA	concurrent time domain multiple access
cvs	comma-separated variables

D

d	(1) derivative; (2) differential as in dx/dt; (3) deci, prefix meaning 0.1; (4) depth; (5) day
D	diameter; also dia and ϕ or derivative time of a controller
DA	data access
D/A	digital to analog
DAC	device access code; digital-to-analog converter
DAE	differential algebraic equation
DAMPS	digital advanced mobile phone system or service
dB	decibels
DBPSK	differential binary phase shift keying
DC	diagnostic coverage
DC or dc	direct current
DCE	data communications equipment
DCOM	distributed COM
DCS	distributed control system
DD	data definition or dangerous component failure is detected in a leg, or a device description written in using DDL
DDC	direct digital control
DDE	dynamic data exchange
DDL	device description language (an object-oriented data modeling language currently supported by PROFIBUS, FF, and HART)
deg	degree; also °(π/180 rad)
DEMUX	demultiplexer
DES	data encryption standard
DFIR	diffused infrared
DG	directed graph
DH	data highway
DI	discrete (digital) input
dia	diameter; also D and ϕ
DIAC	dedicated inquiry access code
DIR	diffused infrared
DIS	draft international standard

DIX	Digital-Intel-Xerox (DIX is original specification that created the *de facto* Ethernet standard; IEEE 802.3 came later after Ethernet was well established)
d(k)	unmeasured disturbance
D(k)	measured disturbance
DLE	data link escape
DLL	dynamic link library
DMM	digital multimeter
DO	dissolved oxygen or discrete (digital) output
DP	decentralized periphery
d/p cell	differential pressure transmitter (a Foxboro trademark)
DPDT	double pole double throw (switch)
DQPSK	differential quadrature phase shift keying
DSL	digital subscriber line
DSR	direct screen reference
DSSS	direct sequence spread spectrum
DT	dead time (seconds or minutes)
DTE	data terminal equipment
DTM	device type manager (an active-X component for configuring an industrial network component; a DTM "plugs into" an FDT)
DU	dangerous component failure occurred in leg but is undetected
DVM	digital voltmeter

E

e	(1) error; (2) base of natural (Naperian) logarithm; (3) exponential function; also exp (–x) as in e^{-x}
E	(1) electric potential in volts; (2) scientific notation as in 1.5E–03 = 1.5×10^{-3}
E{.}	expected value operator
EAI	enterprise application integration
EAM	enterprise asset management
EBCDIC	extended binary code for information interchange
EBR	electronic batch records
EDS	electronic data sheet (DeviceNet)
E/E/PE	electrical/electronic/programmable electronic
E/E/PES	electrical/electronic/programmable electronic system
EFD	engineering flow diagram
e.g.	*exempli gratia*: for example
EHC	electrohydraulic control
EHM	equipment health management
E&I	electrical and instrumentation
e(k)	feedback error
E.L.	elastic limit
emf	(1) electromotive force (volts); (2) electromotive potential (volts)
EMI	electromagnetic interference
EMI/RFI	electromagnetic and radio-frequency interference
$e_m(k)$	process/model error
EN	European standard
EPA	enhanced performance architecture
EPC	engineering-procurement-construction (firm)
EPCM	engineering, procurement, and construction management (companies)
EQ or eq	equation
ERM	enterprise resource manufacturing
ERP	enterprise resource planning or effective radiated power
ESD	emergency shutdown (system)
ESN	electronic serial number
exp	exponential function as in exp (–at) = e^{-at}; also e

F

f	frequency; also freq
F	farad, symbol for derived SI unit of capacitance, ampere·second per volt, A·s/V
°F	Fahrenheit degrees [$t_{°C} = (t_{°F} - 32)/1.8$]
FAT	factory acceptance testing
FBAP	function block application process (FF)
FBD	function block diagram
FCC	fluidized catalytic cracker
FCOR	filtering and correlation (method)
FCS	frame check sequence
FDE	fault disconnection electronics
FDL	fieldbus data link
FDMA	frequency division multiple access
FDT	field device tool (an MS-Windows-based framework for engineering and configuration tools)
FE	final elements
FEED	front end engineering and design
FES	fixed end system
FF or F.F.	Foundation Fieldbus
FF-HSE	Foundation Fieldbus, high-speed Ethernet
FH	frequency hopping
fhp	fractional horsepower (e.g., 1/4 HP motor)
FHSS	frequency hopped spread spectrum
FIFO	first-in, first-out
Fig.	figure
FISCO	Fieldbus Intrinsic Safety COncept
fl.	fluid
fl.oz.	fluid ounces (=29.57 cc)
FMEA	failure mode and effects analysis
FMS	fieldbus message specification or fieldbus messaging services/system
FNC	function byte
FO	fiber optic
FOP	fiber-optic probe
fp or f.p.	freezing point
FPM or fpm	feet per minute (=0.3048 m/min)
fps or ft/s	feet per second (=0.3048 m/s)
FRM	frequency response method
FS or fs	full scale

FSC	fail safe controller
FSK	frequency shift keying
FTA	fault tree analysis
FTP	file transfer protocol
FTS	fault tolerant system

G

g	acceleration due to gravity (=9.806 m/s^2)
G	giga, prefix meaning 10^9 or process gain
gal	gallon(s) (=3.785 liters)
GB	giga-byte, 1,000,000,000 bytes
GbE	gigabit Ethernet
gbps	gigabits per second
G_c	feedback controller transfer function
g-cal	gramcalorie; also cal, *q.v.*
G_d	unmeasured disturbance transfer function
G_D	measured disturbance transfer function
G_D	approximate feedforward transfer function model
GEOS	geosynchronous Earth orbit satellites
G_{ff}	feedforward controller transfer function
GHz	giga-hertz
GIAC	general inquiry access code
GLR	generalized likelihood ratio
G-M	Geiger-Mueller tube, for radiation monitoring
G_m	model transfer function
G_p	process transfer function
gph	gallons per hour (=3.785 lph)
GPM or gpm	gallons per minute (=3.785 lpm)
GPS	global positioning satellite or system
gr	gram
grn	green (wiring code color for grounded conductor)
GSD	Profibus version of an electronic data sheet
GUI	graphical user interface
Gy	gray, symbol for derived SI unit of absorbed dose, joules per kilogram, J/kg

H

h	(1) height; (2) hour
H	(1) humidity expressed as pounds of moisture per pound of dry air; (2) henry, symbol of derived SI unit of inductance, volt· second per ampere, V·s/A
HAZOP	HAZard and OPerability studies
HC	horizontal cross-connect
HAD	historical data access
HART	highway accessible remote transducer
HEC	header error check
HFE	human factors engineering
HFT	hardware fault tolerance
hhv	higher heating value
HIPPS	high-integrity pressure protection system
HIPS	high-integrity protection systems
HIST	host interoperability support test
HMI	human–machine interface
H1	field-level fieldbus; also refers to the 31.25 kbps instrinsically safe SP-50, IEC61158-2 physical layer
hor.	horizontal
HP or hp	horsepower (U.S. equivalent is 746 W)
H&RA	hazard and risk analysis
HSE	high-speed Ethernet (host-level fieldbus)
HSI	human–system interface
HTML	hypertext markup language
HTTP	hypertext transfer protocol
HVAC	heating, ventilation, and air conditioning
H/W	hardware
Hz	hertz, symbol for derived SI unit of frequency, one per second (1/s)

I

I	integral time of a controller in units of time/repeat
IA	instrument air
IAC	inquiry access code
IAE	integral of absolute error
ibidem	in the same place
IC	intermediate cross-connect
I&C	instrumentation and control or information and control
ICA	independent computing architecture
ICCMS	inadequate core cooling monitoring system
ICMP	Internet control message protocol
ID	inside diameter
i.e.	*id est*: that is
I&E	instrument and electrical
IEH	*Instrument Engineers' Handbook*
IETF	Internet engineering task force
IIS	Internet information server
IL	instruction list
ILD	instrument loop diagrams
IMC	internal model control
in.	inch (=25.4 mm)
in-lb	inch-pound (=0.113 N × m)
I/O	input/output
IP	Internet protocol
I-P	current to pressure conversion
IPL	independent protection layer
IR	infrared
IRQ	interrupt request queue
IS	intermediate system
ISE	integral of squared error
ISM	industrial, scientific, medical
ISP	Internet service provider or interoperable system project
IT	information technology (as in IT manager or IT department)
ITAE	integral of absolute error multiplied by time
ITSE	integral of squared error multiplied by time

ITT	intelligent temperature transmitters
IXC	interexchange carrier

J

J	joule, symbol for derived SI unit of energy, heat, or work, newton-meter, N·m
JIT	just-in-time manufacturing

K

k	kilo, prefix meaning 1000
K	kelvin, symbol for SI unit of temperature or process gain (dimensionless)
Kbs, Kbps	kilo bits per second
KBs	kilo bytes per second
k-cal	kilogram-calories (=4184 J)
kg	kilogram symbol for basic SI unit of mass
kg-m	kilogram-meter (torque, =7.233 foot-pounds)
kip	thousand pounds (=453.6 kg)
km	kilometers
K_p	proportional gain of a PID controller, q.v.
kPa	kilo-pascals
kVA	kilovolt-amperes
kW	kilowatts
kWh	kilowatt-hours (=3.6×10^6 J)

L

l	liter (=0.001 m^3 = 0.2642 gallon)
L	(1) length; (2) inductance, expressed in henrys
LAN	local area network
LAS	link active scheduler (FF)
lat	latitude
lb	pound (=0.4535 kg)
LCD	liquid crystal display
LCM	life cycle management
LCSR	loop current step response
LD	ladder diaphragm
LDP	large display panel
LEC	local exchange carrier
LED	light-emitting diode
LEL	lower explosive limit
LEOS	low Earth orbit satellites
lim. or lim	limit
lin.	linear
liq.	liquid
LLC	logical link control
lm	lumen, symbol for derived SI unit of luminous flux, candela·steradian, cd·sr
ln	Naperian (natural) logarithm to base e
LNG	liquefied natural gas
LOC	limiting oxygen concentration
log or $\log_{10}$	logarithm to base 10; common logarithm
long.	longitude
LOPA	layers of protection analysis
LP	liquefied petroleum or propane gas
lph	liters per hour (0.2642 gph)
lpm	liters per minute (0.2642 gpm)
LQG	linear quadratic Gaussian
LRC	longitudinal redundancy check
LSB	least significant bit
LTI	linear time-invariant
LVDT	linear variable differential transformer
lx	lux, symbol for derived SI unit of illuminance, lumen per square meter, lm/m^2

M

m	(1) meter, symbol for basic SI unit of length; (2) mulli, prefix meaning 10^{-3}; (3) minute (temporal), also min
M	(1) thousand (in commerce only); Mach number; (2) molecular weight; mole; (3) mega, prefix meaning 10^6
mA or ma	milliamperes (=0.001 A)
MAC	medium access control
MACID	medium access control identifier
MAP	manufacturing automation (access) protocol
MAU	media access unit
MAWP	maximum allowable working pressure
max	maximum
MB	mega-byte, 1,000,000 bytes
Mbs, mbps	megabits per second
MBs	mega bytes per second
MC	main cross-connect
mCi or mC	millicuries (=0.001 Ci)
m.c.p.	mean candle power
MCP	main control panel
MDBS	mobile database station
MDIS	mobile data intermediate system
med.	medium or median
MEDS	medium Earth orbit satellites
m.e.p.	mean effective pressure
MES	manufacturing execution system or management executive system or mobile end station
MFD	mechanical flow diagram
mfg	manufacturer or manufacturing
mg	milligrams (=0.001 g)
MHz	megahertz
mho	unit of conductance, replaced by siemens, S, *q.v.*
mi	miles (=1.609 km)
MI	melt index
MIB	management information base
micro	prefix = 10^9; also μ (mu) or μm and sometimes u, as in ug or μg, both meaning microgram (=10^{-9} kg)
micron	micrometer (=10^{-6} m)
MIMO	multiple-input multiple-output
MIMOSA	machinery information management open system alliance

min	(1) minutes (temporal), also m; (2) minimum; (3) mobile identification number
MIS	management information system
ml	milliliters (=0.001 l = 1 cc)
mm	millimeters or millimicrons (=0.001 m)
mmf	magnetomotive force in amperes
MMI	man–machine interface
MMS	machine monitoring system or manufacturing message specification
MOC	management of change
MODBUS	a control network
MODEM	modulator/demodulator
mol	mole, symbol for basic SI unit for amount of substance
mol.	molecules
MOON	M out of N voting system
MOSFET	metallic oxide semiconductor field-effect transistor
mp or m.p.	melting point
MPa	megapascal (10^6 Pa)
MPC	model predictive control
mph	miles per hour (1.609 km/h)
mps or m/s	meters per second
MPS	manufacturing periodic/aperiodic services
mR or mr	milliroentgens (=0.001 R)
mrd	millirads (=0.001 rd)
mrem	milliroentgen-equivalent-man
MRP	material requirement planning or manufacturing resource planning
ms	milliseconds (=0.001 s)
MS	Microsoft
MSA	metropolitan statistical areas
MSB	most significant bit
MSD	most significant digit
MSDS	material safety data sheet
MT	measurement test
MTBF	mean time between failures
MTSO	mobil telephone switching offices
MTTF	mean time to failure
MTTFD	mean time to fail dangerously
MTTFS	mean time to spurious failure
MTTR	mean time to repair
MTU	master terminal unit
MUX	multiplexer
MVC	minimum variance controller
MW	megawatts (=10^6 W)

N

n	(1) nano, prefix meaning 10^{-9}; (2) refractive index
N	newton, symbol for derived SI unit of force, kilogram-meter per second squared, $kg \cdot m/s^2$
N_0	Avogadro's number (=6.023×10^{23} mol)
NAP	network access port/point
NAT	network address translation
NC	numeric controller
NDIR	nondispersive infrared
NDM	normal disconnect mode
NDT	nondestructive testing
NEC	National Electrical Code
NESC	National Electrical Safety Code
NEXT	near end cross talk
nF	nanofarad
NIC	network interface card
nm	nanometer (10^{-9} meter)
NRM	normal response mode
NRZ	nonreturn to zero (NZR refers to a digital signaling technique)
NTP	network time protocol
NUT	network update time

O

OD	outside diameter
ODBC	open database connectivity or communication
oft	optical fiber thermometry
ohm	unit of electrical resistance; also Ω (omega)
OJT	on-the-job training
OLE	object linking and embedding
OLE_DB	object linking and embedding database
OPC	object link embedding (OLE) for process control
or	orange (typical wiring code color)
OS	operator station or operating system
OSEK	German for "open system interfaces for in-car electronics"
OSFP	open shortest path first
OSI	open system interconnect (model) or open system integration
OSI/RM	open system interconnect / reference model
OT	operator terminal
OTDR	optical time domain reflectometers
oz	ounce (=0.0283 kg)

P

p	(1) pressure; (2) pico, prefix meaning 10^{-12}
Pa	pascal, symbol for derived SI unit of stress and pressure, newtons per square meter, N/m^2
PA	plant air
PAN	personal area network
Pas	pascal-second, a viscosity unit
PAS	process automation system (successor to DCS)
PB	proportional band of a controller in % (100%/controller gain)
PC	personal computer (MS-Windows based)
PCA	principal component analysis
PCCS	personal computer control system

PCL peer communication link
PCS process control system or personal communication services
pct percent; also %
PD positive displacement or proportional and derivative
PDA personal digital assistant
PDF probability density function
PdM predictive maintenance
PDU protocol data unit
PE polyethylene
PES programmable electronic system
pf picofarad ($=10^{-12}$ F)
PF or p.f. power factor
PFC procedure functional chart
PFD (1) process flow diagram; (2) probability of failure on demand
PFDavg average probability of failure on demand
pH acidity index (logarithm of hydrogen ion concentration)
PHA process hazards analysis
pi or pl Pouiseville, a viscosity unit
PI proportional and integral
PID proportional, integral, and derivative (control modes in a classic controller)
P&ID piping (process) and instrumentation diagram (drawing)
PIMS process information management system
PLC programmable logic controller
PLS physical layer signaling or projection to latent structures
PMA physical medium attachment
PMBC process model-based control
PMF probability mass function
ppb parts per billion
ppm parts per million
PPM pulse position modulation
PPP point-to-point protocol
ppt parts per trillion
precip precipitate or precipitated
PSAT pre-start-up acceptance test
psi or PSI pounds per square inch (=6.894 kPa)
PSI pre-start-up inspection
PSIA or psia absolute pressure in pounds per square inch
PSID or psid differential pressure in pounds per square inch
PSIG or psig above atmospheric (gauge) pressure in pounds per square inch
PSK phase shift keying
PSM process safety management
PSSR pre-start-up safety review
PSTN public switched telephone network
PSU post-start-up
pt (1) point; (2) part; (3) pint (=0.4732 liter)
PT pass token
PTB Physikalisch-Technische Bundesanstalt
PV process variable (measurement) or the HART primary variable
PVC polyvinyl chloride
PVDF polyvinylidene fluoride
PVLO process variable low (reading or measurement)
PVHI process variable high (reading or measurement)

Q

q (1) rate of flow; (2) electric charge in coulombs, C
q^{-1} backward shift operator
Q quantity of heat in joules, J, or electric charge
°Q Quevenne degrees of liquid density
QA quality assurance
QAM quadrature amplitude modulation
QoS quality of service
QPSK quadrature phase shift keying
qt quart (0.9463 liter)
q.v. *quod vide*: which see
QV quaternary variable

R

r radius; also rad
r^2 multiple regression coefficient
R (1) resistance, electrical, ohms; (2) resistance, thermal, meter-kelvin per watt, m·K/W; (3) gas constant ($=8.317 \times 10^7$ erg·mol^{-1}, °C^{-1}); (4) roentgen, symbol for accepted unit of exposure to x and gamma radiation ($=2.58 \times 10^{-4}$ C/kg)
rad (1) radius; also r; (2) radian, symbol for SI unit of plane angle measurement or symbol for accepted SI unit of absorbed radiation dose (=0.01 Gy)
RAID redundant array of inexpensive disks
RAM random access memory
RASCI responsible for, approves, supports, consults, informed
RCU remote control unit
R&D research and development
RDP remote desktop protocol
Re Reynolds number
rem measure of absorbed radiation dose by living tissue (*r*oentgen *e*quivalent *m*an)
rev revolution, cycle
RF or rf radio-frequency
RFC request for comment (an Internet protocol specification)
RFI radio-frequency interference
RFQ request for quotes
RH relative humidity
RI refractive index
RIP routing information protocol

r(k)	set point
RMS or rms	square root of the mean of the square
RNG	rung number
ROI	return on investment
ROM	read-only memory
RPC	remote procedure call (RFC1831)
RPG	remote password generator
RPM or rpm	revolutions per minute
rps	revolutions per second
RRF	risk reduction factor
RRT	relative response time (the time required to remove 90% of the disturbance)
RS	recommended standard
RSA	rural service areas
RTD	resistance temperature detector
RTO	real-time optimization or operation
RTOS	real-time operating system
RTR	remote transmission request
RTS	ready (or request) to send
RTS/CTS	request to send/clear to send
RTU	remote terminal unit
RWS	remote work station

S

s	second, symbol for basic SI unit of time, also sec; or Laplace variable
S	siemens, symbol for derived SI unit of conductance, amperes per volt, A/V
SAP	service access point
sat.	saturated
SAT	site acceptance test or supervisory audio tone
SC	system codes
SCADA	supervisory control and data acquisition
SCCM	standard cubic centimeter per minute
SCFH	standard cubic feet per hour
SCFM	standard cubic feet per minute (airflow at 1.0 atm and 70°F)
SCM	station class mark
SCMM	standard cubic meter per minute
SCO	synchronous connection oriented
SCR	silicon controlled rectifier
SD	component in leg has failed safe and failure has been detected
SDN	send data with no acknowledge
SDS	smart distributed system
SEA	spokesman election algorithm
sec	seconds; also s
SER	sequence of event recorder
SFC	sequential function chart
SFD	system flow diagram or start of frame delimiter
SFF	safe failure fraction
SFR	spurious failure rate
SG or SpG	specific gravity; also sp.gr.
SID	system identification digit (number)
SIF	safety instrumented function
SIG	special interest group
SIL	safety integrity level
sin	sine, trigonometric function
SIS	safety instrumented system
SISO	single-input single output
SKU	stock keeping units
SLC	safety life cycle
slph	standard liters per hour
slpm	standard liters per minute
SMR	specialized mobile radio
SMTP	simple mail transfer (management) protocol
SNMP	simple network management protocol
SNR	signal-to-noise ratio
SOAP	simple object access protocol (an Internet protocol that provides a reliable stream-oriented connection for data transfer)
SOE	sequence of events
SOP	standard operating procedure
SP	set point
SPC	statistical process control
SPDT	single-pole double-pole throw (switch)
sp.gr.	specific gravity; also SG
SPRT	standard platinum resistance thermometer
sq	square; also □
SQC	statistical quality control
SQL	standard query language
sr	steradian, symbol for SI unit of solid angle measurement
SRD	send and request data with reply
SRS	safety requirements specification
SS	stainless steel
SSL	secure socket layers
SSU	Saybolt universal seconds
ST	structual text, also a fiber optic connector type
std.	standard
STEP	standard for the exchange of product model data
STP	shielded twisted pair
STR	spurious trip rates
SU	component in leg has failed safe and failure has not been detected
SV	secondary variable
S/W	software
s_y^2	sample variance of output y

T

t	(1) ton (metric, = 1000 kg); (2) time; (3) thickness
T	(1) temperature; (2) tera, prefix meaning 10^{12}; (3) period (=1/Hz, in seconds); (4) tesla, symbol for derived SI unit of magnetic flux density, webers per square meter, Wb/m^2

$T\frac{1}{2}$	half life
tan	tangent, trigonometric function
Tau	process time constant (seconds)
TCP	transmission (or transport) control protocol
TCP/IP	transmission control protocol/Internet protocol
td	process dead time (seconds)
T_d	derivative time (in seconds) of a PID controller
TDM	time division multiplexing
TDMA	time division multiple access
TDR	time domain reflectometry
TFT	thin film transistor
Ti	integral time (in seconds) of a PID controller
TI	time interval between proof tests (test interval)
TMR	triple modular redundancy
TOP	technical office protocol
TQM	total quality management
T.S.	tensile strength
TSR	terminate and stay resident
TV	tertiary variable
°Tw	Twadell degrees of liquid density

U

u	prefix = 10^{-6} when the Greek letter μ is not available
UART	universal asynchronous receiver transmitter
UBET	unbiased estimation
UCMM	unconnected message manager
UDP	user/universal data protocol (an Internet protocol with low overhead but no guarantee that communication was successful)
UEL	upper explosive limit
$u_{fb}(k)$	feedback controller output
UFD	utility flow diagram
$u_{ff}(k)$	feedforward controller output
UHF	ultrahigh frequency
UHSDS	ultrahigh-speed deluge system
u(k)	controller output
UML	universal modeling language
UPS	uninterruptible power supply
UPV	unfired pressure vessel
USB	universal serial bus
UTP	unshielded twisted pair
UUP	unshielded untwisted pair
UV	ultraviolet

V

v	velocity
v or V	volt, symbol for derived SI units of voltage, electric potential difference and electromotive force, watts per ampere, W/A
VBA	visual basic for applications
VCR	virtual communication relationship
VDU	video display unit
vert.	vertical
VFD	variable frequency drive
VFIR	very fast infrared
VHF	very high frequency
VMS	vibration monitoring system
VPN	virtual private network
VR	virtual reality
VRML	virtual reality modeling language
vs.	versus
V&V	verification and validation

W

w	(1) width; (2) mass flow rate
W	(1) watt, symbol for derived SI unit of power, joules per second, J/s; (2) weight; also wt
w.	water
WAN	wide area network
Wb	weber, symbol for derived SI unit of magnetic flux, volt·second, V·s
WG	standard (British) wire gauge
wh	white (wiring code color for AC neutral conductor)
WI	wobble index
WLAN	wireless local area network
WPAN	wireless personal area network
WS	workstation
wt	weight; also W

X

X	reactance in ohms
XML	extensible markup language
x ray	electromagnetic radiation

Y

y(k)	process output
yd	yard (=0.914 m)
yr	year

Z

Z	(1) atomic number (proton number); (2) electrical impedance (complex) expressed in ohms
zeb	zero energy band

GREEK CHARACTERS

$\eta(b)$	normalized performance index
$\eta(b+h)$	extended horizon performance index
λ	desired closed-loop time constant

$\lambda^{DU} = 1/MTTF^{DU}$	failure rate for dangerous undetected faults
$\lambda^{S} = 1/MTTF^{S}$	spurious trip rate
μm	microns
θ	process dead time (seconds or minutes)
σ^2	population variance
σ_y^2	population variance in output y
σ_{mv}^2	theoretical minimum variance
τ	process time constant (seconds or minutes)
τ_F	PV filter time constant
ψ	impulse weights

NOTES

1. Whenever the abbreviated form of a unit might lead to confusion, the abbreviation should not be used and the name should be written out in full.
2. The values of SI equivalents were rounded to three decimal places.
3. The words meter and liter are used in their accepted spelling forms instead of those in the standards, namely, metre and litre, respectively.

SOCIETIES AND ORGANIZATIONS

ACC	American Chemistry Council
ACS	American Chemical Society
AGA	American Gas Association
ANSI	American National Standards Institute
APHA	American Public Health Association
API	American Petroleum Institute
ARI	Air Conditioning and Refrigeration Institute
ASA	American Standards Association
ASCE	American Society of Civil Engineers
ASME	American Society of Mechanical Engineers
ASRE	American Society of Refrigeration Engineers
ASTM	American Society for Testing and Materials
BSI	British Standards Institution
CCITT	Consultative Committee for International Telegraphy and Telephony
CENELEC	European Committee for Electrotechnical Standardization
CII	Construction Industry Institute
CIL	Canadian Industries Limited
CNI	ControlNet International
CSA	Canadian Standards Association
DARPA	Defense Advanced Research Projects Agency
DIN	Deutsche Institut fuer Normung
DOD	Department of Defense (United States)
DOE	Department of Energy (United States)
EIA	Electronic Industries Association
EIA/TIA	Electrical Industries Alliance/Telecommunications Industries Association
EPA	Environmental Protection Agency (United States)
EPRI	Electric Power Research Institute
FCI	Fluid Control Institute
FDA	Food and Drug Administration (United States)
FF	Fieldbus Foundation
FIA	Fire Insurance Association
FM	Factory Mutual
FPA	Fire Protection Association
HCF	HART Communication Foundation
IAEI	International Association of Electrical Inspectors
ICE	Institute of Civil Engineers
ICEA	Insulated Cable Engineer's Association
IEC	International Electrotechnical Commission
IEEE	Institute of Electrical and Electronic Engineers
IETF	Internet Engineering Task Force
IPTS	International Practical Temperature Scale
IrDA or IRDA	Infrared Data Association
ISA	Instrumentation, Systems, and Automation Society (formerly Instrument Society of America)
ISO	International Standards Organization
ISTM	International Society for Testing Materials
JBF	Japan Batch Forum
KEPRI	Korean Electric Power Research Institute
LPGA	National LP-Gas Association
MCA	Manufacturing Chemists' Association
NAMUR	German standardization association for process control (Normenarbeitsgemeinschaft für Meß- und Regelungstechnik in der chemischen Industrie)
NASA	National Aeronautics and Space Administration