FLUIDICS
Components and Circuits

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Preface

Fluidics has developed in a rather unbalanced way since it crystallized as a new branch of Control Systems in the late 1950's. Some areas have received considerable attention both in North America and Europe, particularly in relation to aerospace applications. However, in the purely industrial field little advance has been made in the application of fluidic–pneumatic control systems until comparatively recently due to the lack of commercial viability of the majority of devices available. One exception to this has been the widespread use of miniaturized moving-part pneumatic devices in Eastern Europe mainly for Process Control applications.

It is clear that a considerable amount of practical knowledge exists on both individual device performance and also circuits. Although much of this has arisen from aerospace applications, with consequent rather restricted information dissemination, it is gradually passing into the industrial field. Many introductory articles and research papers on fluidics have appeared in the literature, which have tended to produce a gap in understanding between the specialist and the non-specialist. We have attempted to bridge this gap by writing a book which we hope will appeal both to the specialist and layman alike.

The original material for the book was written for a Fluidics course organized by the authors at Birmingham University (Easter 1967) and used again in slightly modified form for a similar course in 1968. Since that time substantial revisions and additions to the material have been made both as a result of experience gained in running the courses and also new research in the field. One of the difficulties experienced has been writing an up-to-date text at a time of rapid technological change in Fluidics.

Although some of the topics dealt with in the book are not directly related, we have tried to follow a logical development of the subject. Chapter 1 is an introduction to all the well-known non-moving part devices and sensors which may be found in fluidic systems. The explanation is simple and essentially non-mathematical so that the non-specialist may easily grasp the main features. Many of the devices are described in more detail in later chapters. In Chapters 2 and 3 the fluid mechanics of systems components using a lumped and distributed parameter representation is developed on a general basis together with the mechanism of fluid flow within fluidic devices.

At this point the book divides into two distinct sections. Chapters 4 and 5 deal exclusively with pure fluid analogue devices and methods of signal shaping for fluidic circuits. Chapters 6 to 14 deal with many aspects of both moving and non-moving part digital fluidic devices. Particular attention is paid to the description of standard system sub-assemblies (such as counters, encoders, etc.) and also system organization. Finally, Chapter 15 deals briefly with some of the graphic techniques available for obtaining system operating-conditions in both digital and analogue circuits.

A difficulty in writing a compendium of material of this kind is that notation differs widely between authors; symbols for fluidic devices are by no means standardized. Some attempt has been made to rationalize both of these, simply in order to avoid confusion in any one chapter, but neither notation nor symbols have been standardized completely and the authors hope that the compromise will be acceptable to the reader.

A further difficulty is that it is impossible to cover every reference in the vast amount of literature available on fluidics and the choice of papers to which reference is made inevitably reflects the interest of the authors. There will doubtless be many excellent references not discussed.

The authors would like to acknowledge the generous support of the Science Research Council for a considerable proportion of their research work, the results from which constantly appear throughout the book. Thanks are also due to the National Coal Board and the Admiralty for contracts which provided further impetus to the research.

It is impossible to end the preface without acknowledging the efforts of those concerned with carrying out the research projects and responsible for many of the results quoted. Drs. N. S. Jones, D. G. Mitchell, B. Jones, and D. A. Retallick were working on the projects while most of the present material was being gathered together, and most thanks are due to them. In the latter stages, discussions with M. K. Addy, P. J. Cleife, R. M. H. Cheng and P. Drazan have been invaluable and we extend our thanks to them also. No book can be written without substantial secretarial aid and we are indebted to Mrs. M. Plant for most of the early work and more recently to Miss R. Croger, Miss J. Nightingale and Mrs. M. Eardley.

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Glossary of Symbols

If a symbol has an alternative use in a specific chapter the chapter is quoted after the definition in parentheses.

A	area
a	local propagation velocity
b	channel width
C	fluid capacitance
C_{12}	$= N_{12}.(P_1/P_2)$
C_D	coefficient of discharge
c	absolute propagation velocity
D	diameter
d	depth, setback (Chapter 7)
E	ratio of dynamic to total pressure
F_w	pressure force on wall
f	frequency or friction coefficient
f_1	non-linear static characteristics of analogue amplifier 1
G	gain
$G(s)$	transfer function
g	gravitational constant
H	fluid inductance or inertance
h	channel height
I	rotary inertia
J	fluid momentum
j	$= \sqrt{-1}$
K	compressible orifice flow constant
K_{12}	$= \dfrac{(P_1/P_2)}{N_{12}} \cdot \dfrac{\partial N_{12}}{\partial(P_1/P_2)}$
L	length
$L_{f,i}$	free and impacting jet potential flow core length respectively
M	weight of fluid (Chapter 2), mass flow rate (Chapter 4), magnitude ratio (Chapter 5)
m	incremental mass flow rate
N	gear ratio
N_{12}	$= W_{12}/W_{crit}$, n_{12} incremental value
n	polytropic constant
P, p	steady state and incremental pressure, total and static pressures respectively (Chapter 4)
ΔP	pressure difference

P_m	mean pressure
Q, q	steady state and incremental volume flow rate
R, r	steady state and incremental resistance
$\mathbf{R}$	gas constant
R_e	Reynolds number
r	radius (Chapter 4)
S	wall offset
$\mathscr{S}$	LaPlace transform, specific weight (pp. 49, 50 only)
T	absolute temperature
t	time
U, u	particle velocity in the x direction
$\bar{u}$	sectional mean velocity
V	volume
v	particle velocity in the y direction
W, w	steady state and incremental weight flow rate, nozzle width (Chapter 1)
$\mathscr{W}$	power
X, x	steady state and incremental distance
$Y(j\omega)$	admittance
$Z(j\omega)$	impedance
Z_{ch}	characteristic impedance
α	wall angle
β	jet deflexion due to control momentum and static pressure forces
β_m	jet deflexion due to control momentum alone
γ	ratio of specific heats (= 1·4 for air)
θ	total jet deflexion
μ	absolute viscosity
ν	kinematic viscosity
ξ	damping ratio
ρ	density
τ	time constant
ϕ	phase angle, jet spread angle (Chapter 4)
ω	angular frequency
ω_r	resonant frequency

Suffices

c	control or input
col	collector
e	emitter
o	output
s	supply

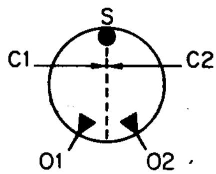
Chapter 3

B	width of nozzle
b	width of jet at distance x from nozzle or slit
$b_{\frac{1}{2}}$	distance between $\frac{1}{2}U$ velocity points in jet
b'	y at point of inflection of velocity profile of jet
C'_p	$(P_\infty - P_b)/(P_\infty - P'_b)$
C_Q, C_Γ	source and vortex strengths
c	$c_r + jc_i = \beta/\alpha$ for laminar jet

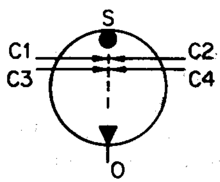
D	setback
d	diameter of circular nozzle, distance apart of vortex rows
E	entrainment parameter—subscripts 1, 2 denote inner and outer edges of jet respectively
G	value set for $\bar{W}_c^*$ in vortex valve
h	distance of reattachment point from nozzle centre line, also nozzle-edge distance, also height of vortex chamber
h_{c_i}, h_{c_0}	distance of inner and outer nozzle edges from jet centre line for curved flow
J	momentum of jet
K	$= J/\rho$ also constant
K_{e_c}, K_{e_0}	calculated and actual K at nozzle
l	mixing length, also distance of reattachment point from nozzle in x direction
m	$= C\alpha/2\beta$ in vortex flow
N	radial Re, also an integer
P_b	average bubble pressure
P'_b	pressure along boundary close to nozzle
$\bar{P}_{cc}$	non-dimensional cut-off control pressure for vortex valve
P_∞	static pressure outside bubble
P'_∞	static pressure downstream of reattachment
$R_{e,o}$	inner and outer radii of vortex chamber
t	a parameter $\tanh\left(\dfrac{\sigma y}{x + x_0}\right)$
U	centre line velocity in jet analyses
U_m	maximum velocity of mean flow
U_R	maximum velocity of reverse flow in bubble
u_v	velocity of propagation of vortices in jet
X	$= r/R_0$ for vortex analysis
x_r	reattachment distance along the wall
α	reciprocal of wavelength of disturbances in jet ($= \alpha_r + j\alpha_i$), a wall angle, angle flow makes with radius in vortex flow analysis, a parameter
β	speed of propagation of disturbance in jet ($= \beta_r + j\beta_i$), a parameter
ε	eddy viscosity
η	$\sigma y/x$; also a co-ordinate
θ	angle between main jet and control jet, also angle subtended by bubble at centre of curvature
κ	a constant in expression of eddy viscosity
ξ^*	distance from one edge of shear layer to where velocity is $\frac{1}{2}U$
σ	turbulent mixing coefficient
ϕ	jet deflection angle

Notation for Analogue Devices

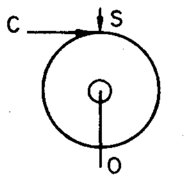
Proportional beam deflection amplifier



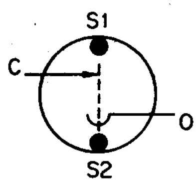
Rectifier



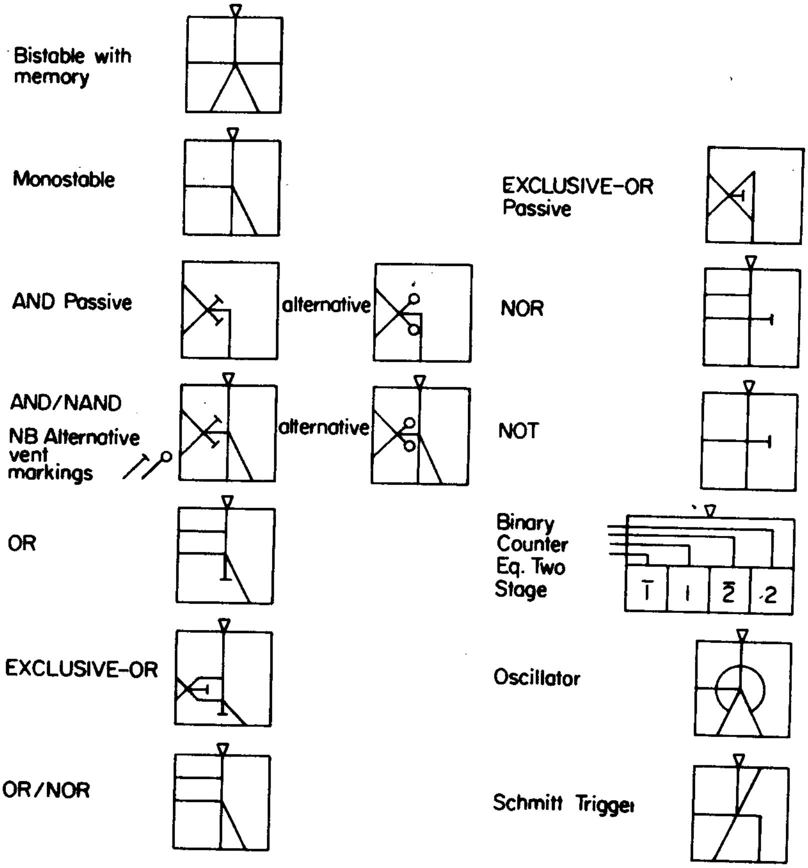
Vortex amplifier



Transverse impact modulator



Notation for Digital Devices



Contents

1

Introduction to Pure Fluid Devices and Sensors

1.1 General

What is Fluidics? Fluidics is a new technology arising from a re-appraisal of a very old technology, namely fluid power and its control. The basic distinction to be drawn between conventional fluid flow engineering and fluidics is that in the former case we are normally concerned only with harnessing fluid power in an economic manner, whereas with fluidics we are thinking in terms of processing information through a fluid medium as well as transmitting power. For this reason the attitude towards the development of fluidic devices and circuits clearly owes as much to the well-established technology of electronics as it does to fluid mechanics. Of course we have been able to control fluids in very sophisticated ways for a long time; but generally the control systems have tended to be limited in performance by the mechanical nature of the control devices, such as spool valves, diaphragms, springs, etc., used in the system. The philosophy of fluidics, on the other hand, has been to examine new devices which use extremely simple mechanical shapes or alternatively rely on fluid mechanic effects within the fluid itself, so that moving parts are eliminated. Such elements are considerably faster than conventional mechanical, electro-mechanical, pneumatic and hydraulic components, and potentially have high reliability. It is these factors which make it technically and economically attractive to process information in a fluid medium for certain applications.

Furthermore, fluidic circuits can operate under severe environmental conditions, when made from suitable materials, without loss of reliability. This increases the possible area of fluidic applications considerably, particularly as electronic components and systems are at a disadvantage in these conditions. Generally fluidic control devices are never expected to compete with electronics where speed of operation is important, such as in general purpose computing; nevertheless, there are many applications where this speed is not required but rather a premium is set on cheapness, reliability and an ability to function in adverse environments. In these circumstances fluidic devices show up in a more favourable light and may be regarded as complementing the existing range of control system components.

Generally, any fluid may be used in fluidic control elements provided the designs conform to the fluid mechanic principles involved. However, as far as industrial fluidics is concerned, the usual working fluid is air because of its relative cheapness, availability and ease of use. Special applications using other common fluids such as hydraulic oil and water are mainly still in the experimental stage.

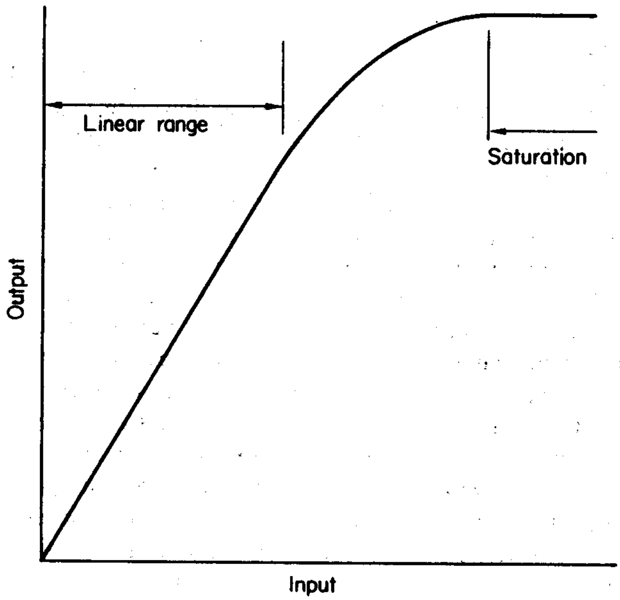


Fig. 1.1 Analogue device

1.2 Classification of Element Types

Broadly speaking, elements may be divided into two categories, depending on whether they are to be used for analogue or digital circuit applications. In analogue circuits continuous change or modulation of the signals occur in the system, with each element in the circuit bearing a direct relationship between the input and output signals. Fig. 1.1 shows a typical characteristic for analogue elements which, in practical designs, always exhibit a limited linear or proportional range and a corresponding non-linear range associated with the overloaded or saturated condition.

A digital or switching device operates on the basis of discrete signal changes; that is, only one output signal change is produced when the input signal magnitude is raised above a minimum level or switching point, as shown in Fig. 1.2. It is seen that such elements respond only to two signal

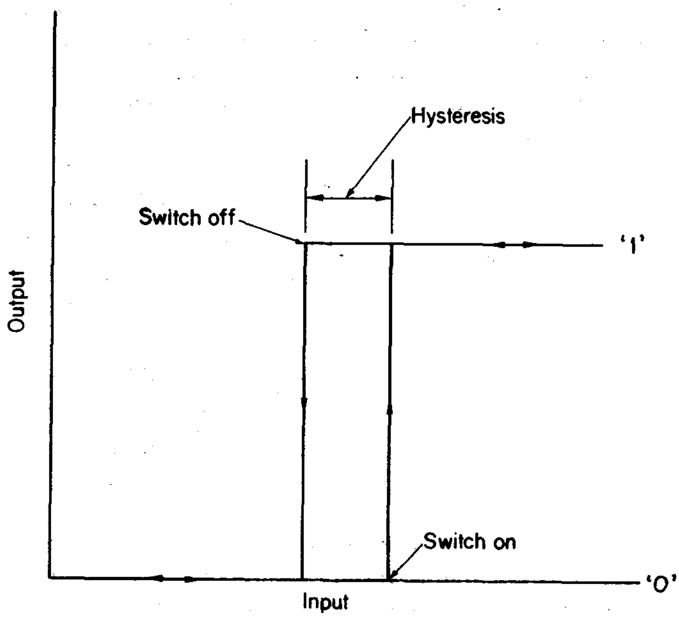


Fig. 1.2 Digital device

levels (usually designated '1' and '0') and, unlike analogue elements, are ideally immune from intermediate signal levels. The resulting switching action may, in practice, also produce a switching deadband or hysteresis loop signifying a different switching 'on' point to the switching 'off' point due to internal energy losses within the device.

Further classifications for elements may be made on the basis of whether a separate energy supply is required. If no energy is added, the device is termed passive as distinct from an active device which does require a separate supply. A usual requirement for an active device is that the output signal should be amplified compared with the input or control signal.