THE DEVELOPMENT OF A HIGH PERFORMANCE LASER DOPPLER VELOCIMETER FOR FLUID MECHANICS AND ACOUSTICS RESEARCH APPLICATIONS

by

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SUMMARY

It is the purpose of this present study to delineate the design criteria and operating principles of a high speed, digital laser Doppler velocimeter that is suitable for a large number of applications in fluid mechanics and acoustics research.

The shortcomings of existing techniques for the measurement of fluid and surface velocities are discussed and the advantages of laser Doppler systems are investigated. Relevant theoretical considerations are presented, with particular reference to the capabilities and limitations of light scattering techniques. A comprehensive review of the currently available methods for optical frequency biasing forms the basis for the development of a high diffraction efficiency acousto-optic cell. The essential and desirable characteristics of a high performance LDV are established and incorporated into the design and construction of a digital signal processing system that uses time domain analysis for the demodulation of velocity and real time information. The system is shown to offer solutions to the serious problems of directional aliasing; signal biasing; spectral broadening and signal dropout and is used with a modified Michelson interferometer to detect the surface velocity of a mechanically driven mirror.


LASER DOPPLER VELOCIMETER
accumul.
discrete
start
stop
reset
auto stop
D.T.B.B.
offset
N
LASER DOPPLER VELOCIMETER
POWER SUPPLY

STATEMENT

This thesis contains no material which has been accepted for the award of any other degree or diploma in any university and, to the best of my knowledge and belief, contains no material previously published or written by another person, except where due reference is made in the text.

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To Helen and my family, as always, I owe the greatest debt.

NOMENCLATURE

a	-	constant
a_r	-	receiver aperture radius
c	-	speed of light
d	-	fringe spacing; grating spacing
d_p	-	particle diameter
$\underset{\sim}{e}_i, \underset{\sim}{e}_s$	-	incident, scattered light beam unit vectors
$\underset{\sim}{e}_{s_n}$	-	n^{th} order scattered light beam unit vector (Fig.13)
f	-	frequency; focal length of a lens
f_a	-	acoustic frequency
f_b	-	bias frequency
f_D	-	Doppler frequency
f_i, f_s	-	frequency of incident, scattered light beam
f_m	-	modulating frequency
f_n	-	frequency of n^{th} order diffracted beam
f_o	-	laser frequency
g	-	Landé g factor
h	-	height of acoustic beam; Planck's constant
i_1, i_2	-	intensity functions
j'	-	quantum number
$\underset{\sim}{k}_i, \underset{\sim}{k}_s$	-	incident, scattered wave vectors; incident, scattered photon momentum vectors
ℓ	-	length of focal volume; length of laser cavity; solenoid length.
ℓ'	-	focal volume dimension (Fig.12); quantum number.
ℓ_a	-	effective probe length
ℓ_m	-	molecular mean free path
ℓ_r	-	minimum probe length
m_j'	-	total angular momentum quantum number
n	-	diffracted order; no. of particles; percentage error; no. of turns.

NOMENCLATURE (Cont'd)

p - phase retardation; elasto-optic coefficient (79)

p_1; $p_{>1}$ probabilities

r - pinhole radius; disc radius

s - Laplacian operator

s, s', s_1', s_2', s_r' - dimensions (Fig.8)

t - time; focal volume thickness

v - velocity

v_a - acoustic velocity

$\underset{\sim}{v}_p$ - particle velocity vector

v_f - fluid velocity; fringe velocity

w - beam width

x_1, x_2 - dimensions (Fig.8)

A - receiving optics aperture

D - e^{-1} diameter of unfocused laser beam

E_1, E_2 - intensities of the two incident beams

E_i, E_s - incident, scattered beam intensities

E_o, E_p - intensity at the centre, at a point p in the focal volume.

F - Gaussian F number

$\underset{\sim}{H}$ - magnetic field intensity

I - coil current

I_o - unattenuated laser intensity

I_θ - scattered beam intensity at an angle θ

$J_n(a)$ - Bessel ftn.

K - propogation constant of sound waves; Cunningham const.

$\underset{\sim}{K}_a$ - incident phonon wave vector.

K_s - scattering coefficient

NOMENCLATURE (Cont'd)

$\underset{\sim}{L}_i$	-	orbital angular momentum vector.
M	-	figure of merit; constant.
N	-	no. of wavefronts; Avogadro's no. ; no. of cycles.
N_p	-	no. of scattering particles.
P	-	hydrostatic pressure
P_a	-	acoustic power
R	-	gas constant
R_r	-	receiver distance from scattering volume
$\underset{\sim}{S}_i$	-	spin angular momentum vector.
T	-	absolute temperature; measurement interval.
$\overline{V}$	-	mean velocity
V_c	-	size of the focal volume
W	-	acoustic beam width
Z	-	const.
α, β, γ	-	angular notation
β	-	modulation index
δ	-	radius of beam waist
δ_s	-	radius of scattered beam waist
ε	-	error due to particle inertia
η	-	refractive index; viscosity
η_1	-	constant
θ	-	angle of incidence
θ_B	-	Bragg angle
θ_n	-	n^{th} order diffraction angle.
λ	-	optical wavelength
λ_i, λ_s	-	incident, scattered wavelengths.
$\underset{\sim}{\mu}$	-	nett magnetic moment vector
μ_B	-	Bohr magneton.

NOMENCLATURE (Cont'd)

ν - kinematic viscosity

ν_o - laser frequency

ρ - density

ρ_p, ρ_f - particle, fluid density

τ_{min} - minimum time of flight

ϕ - angle of inclination of $\underset{\sim}{V}p$; phase angle

ψ_i, ψ_s - incident, scattered wave functions.

ω - angular frequency.

ω_D - angular Doppler frequency

ω_i, ω_s - incident, scattered beam angular frequencies

ω_m - maximum angular turbulence frequency.

ΔA - dimension (Fig. 8)

ΔE - induced change in atomic energy levels.

Δf_c - laser cavity half width

Δf_D - Doppler spectral broadening; Doppler frequency deviation.

Δf_{Ne} - He-Ne laser half line width

Δs - half the length of the focal volume (Fig.8).

$\overline{\Delta x^2}$ - particle Brownian motion

Δy - fringe separation

$\Delta\nu$ - Zeeman frequency shift

$\Delta\Omega$ - solid angle subtended by receiving aperture.

κ - geometric constant

Λ - acoustic wavelength.

Ω - solid angle of acceptance.