ESCOLA POLITÉCNICA DA UNIVERSIDADE DE SÃO PAULO
DEPARTAMENTO DE ENGENHARIA MECÂNICA
PROJETO MECÂNICO

DISPOSITIVO PARA ENSAIO DE PRÓTESES VALVARES

Elcio Hayashi

Prof. Eduardo Akira Misawa
Orientador

1982

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SUMÁRIO

O presente projeto propõe um dispositivo para estudo experimental da dinâmica do escoamento de próteses valvares em regime permanente, para ser utilizado pelos engenheiros e médicos da Divisão de Bio-engenharia do Instituto do Coração do Hospital das Clínicas da Faculdade de Medicina da USP, no estudo das válvulas existentes e no desenvolvimento de novas próteses valvares.

Foi construído um protótipo do dispositivo cujos detalhes estão neste trabalho, juntamente com os resultados experimentais obtidos.

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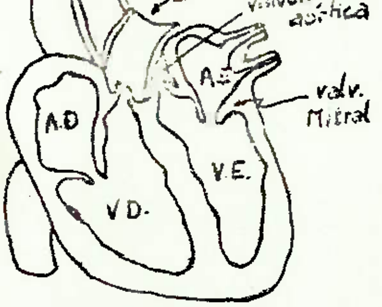
CAPÍTULO I

I - INTRODUÇÃO

I.1 - O CORAÇÃO E A CIRCULAÇÃO SANGUÍNEA

O sistema circulatório pode ser comparado a um circuito hidráulico onde o fluido é o sangue que percorre no interior dos vasos sanguíneos.

O coração, pertencente ao sistema circulatório, pode ser considerado como uma bomba dupla de deslocamento positivo, pulsátil, e bombeia o sangue a todas as partes do organismo em vazões que variam de acordo com suas necessidades (figura 1).



Ele é constituído por quatro câmaras, sendo dois átrios e dois ventrículos. Os ventrículos são os principais responsáveis pela propulsão do sangue.

O coração possui quatro válvulas(de retenção) para poder bombear o sangue. Essas válvulas abrem-se e fecham-se passivamente, dependendo da diferença de pressão à montante e à juzante da válvula. Ainda, o fechamento é auxiliado pelos vórtices que se formam junto à válvula. Elas oferecem uma baixa resistência ao fluxo e fecham-se rapida e perfeitamente possibilitando baixa regurgitação.

Temos, então, as seguintes válvulas:

a) A válvula tricúspide, entre o átrio direito e o ventrículo direito;

b) A válvula pulmonar, entre o ventrículo direito e a artéria pulmonar;

c) A válvula mitral (figura 2), entre o átrio esquerdo e o ventrículo esquerdo;

d) A válvula aórtica (figura 3), entre o ventrículo esquerdo e a aorta.

As vezes, as válvulas cardíacas apresentam anomalias causando aumento da resistência ao fluxo pela abertura menor da válvula (estenose) ou problemas de regurgitação do sangue (refluxo).

Quando estes fatos ocorrem, as vezes, torna-se necessária a substituição da válvula natural por uma válvula cardíaca artificial (Protese Valvar).

Esta substituição ocorre, geralmente, nas válvulas do lado esquerdo do coração (mitral e aórtica), pois o lado esquerdo é uma bomba de maior potência que deve enviar o sangue a todas as partes do organismo.

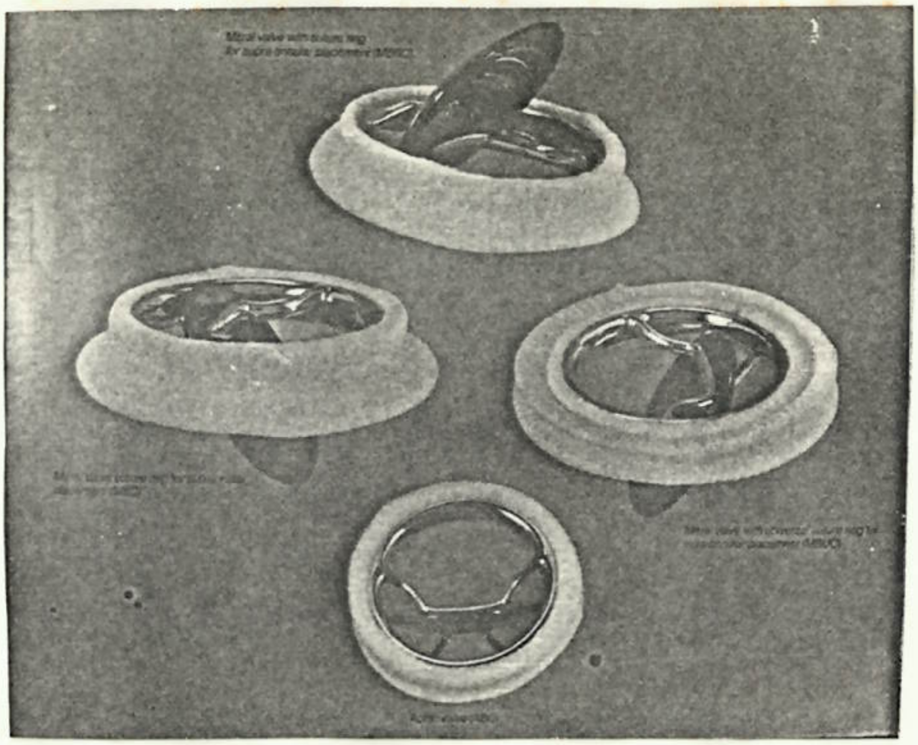


Figura 10 - Válvula "Bjork-Shiley"

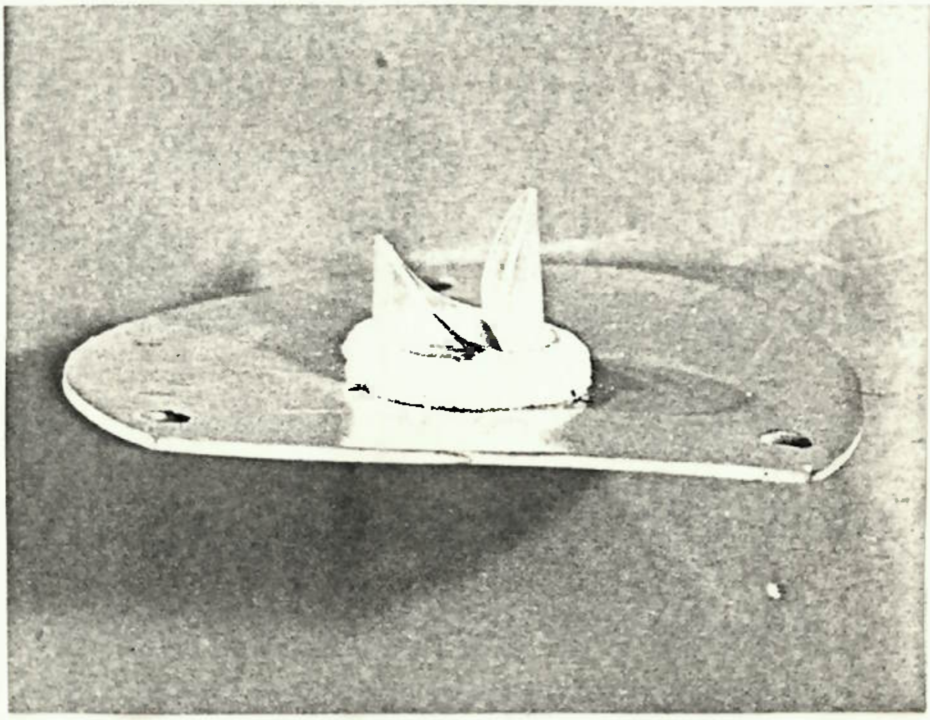


Figura 11 - Modêlo em poliester da válvula de disco curvo basculante (em fase de desenvolvimento).

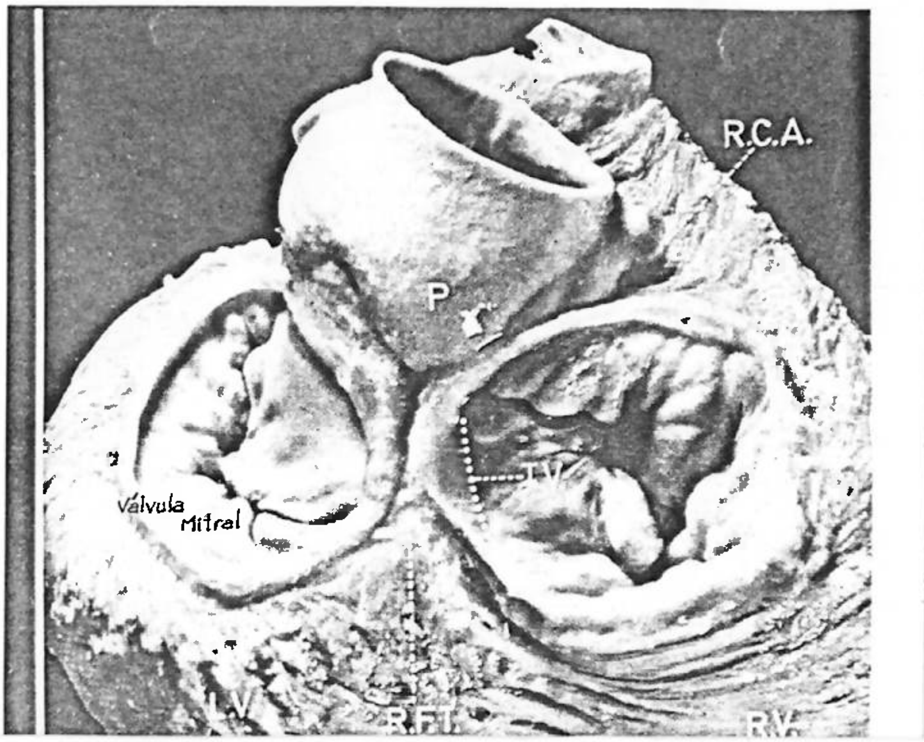


Figura 2 - Válvula Mitral

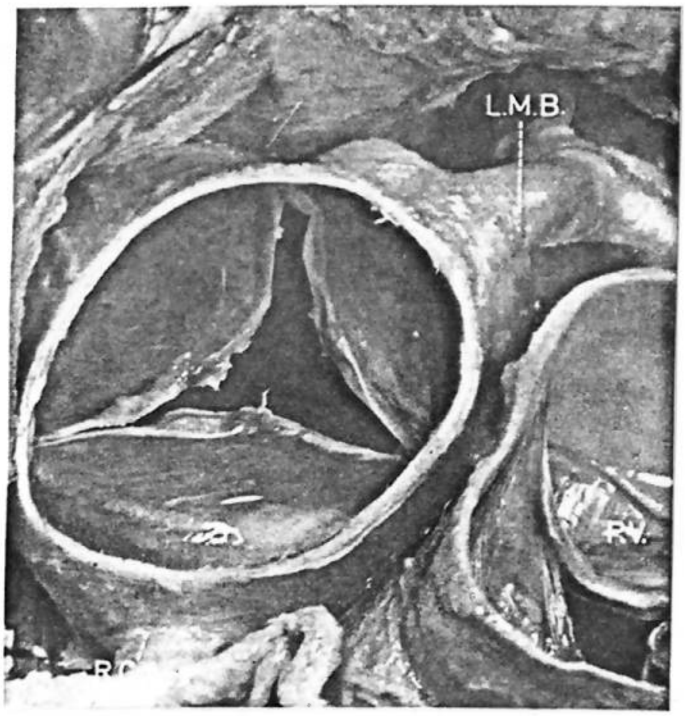


Figura 3 - Válvula Aórtica

CAPÍTULO II

II - AS PRÓTESES VALVARES

II.1 - CONCEPÇÕES DE PRÓTESES VALVARES

Atualmente, existem vários tipos de válvulas cardíacas artificiais (aproximadamente 50), que foram desenvolvidas no decorrer dos anos, tais como:

a) VÁLVULA DE BOLA: que possuem uma esfera de silicone com função de oclusor, encerrada dentro de uma gaiola limitadora de curso (figura 4).

b) VÁLVULAS DE TECIDOS HOMÓLOGOS: são construídas com tecidos biológicos retirados de seres humanos e têm um funcionamento similar às válvulas naturais. O Hospital das Clínicas da Faculdade de Medicina da USP utiliza válvulas de duramater (tecido retirado da membrana que recobre o cérebro). (figura 5).

c) VÁLVULA DE TECIDOS HETERÓLOGOS: são construídas com tecidos biológicos retirados de animais (figura 6).

d) VÁLVULA DE LASCÍNEAS FLEXÍVEIS: são construídas com materiais sintéticos e são similares às válvulas aórticas naturais (figura 7).

e) VÁLVULA DE DISCO: que possuem um disco (de carbono vítreo ou metálico recoberto com carbono pirolítico) como elemento oclusor. O funcionamento é similar à válvula de bola (figuras 8).

f) VÁLVULA DE DISCO BASCULANTE: que possuem um disco basculante em torno de um eixo contido no plano do anel. São muito utilizadas pois seu desempenho é um dos melhores.(figuras 9 e 10).

g) VÁLVULA DE DISCO CURVO BASCULANTE: esta válvula está em fase de desenvolvimento na Divisão de Bio-engenharia do Instituto do Coração do Hospital das Clínicas da Faculdade de Medicina da USP. Sua concepção é semelhante à válvula de disco basculante (figura 11).

II.2 - AS CARACTERÍSTICAS DAS PRÓTESES VALVARES

Segundo Harken, os dez mandamentos das próteses valvares são:

1. Não deve provocar embolia (obstrução do escoamento do sangue);
2. Deve ser quimicamente inerte e não deve danificar os elementos do sangue;
3. Não deve oferecer resistência ao fluxo fisiológico;
4. Deve fechar instantaneamente (menos que 0,05 seg);
5. Deve permanecer fechada durante a fase apropriada do ciclo cardíaco;
6. Deve ter características físicas e geométricas duradouras;
7. Deve ser implantada em posição fisiológica , geralmente, na posição anatômica normal;

Starr-Edwards Ball Valve

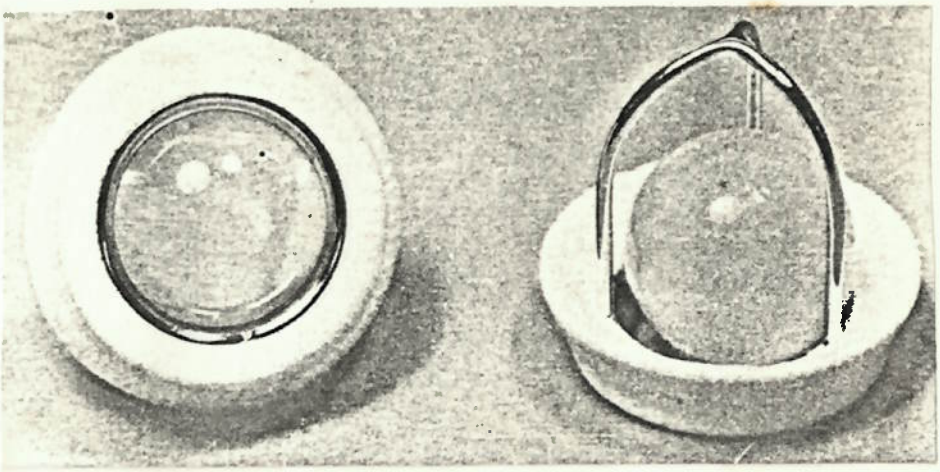


Figura 4 - Válvula "Starr-Edwards"

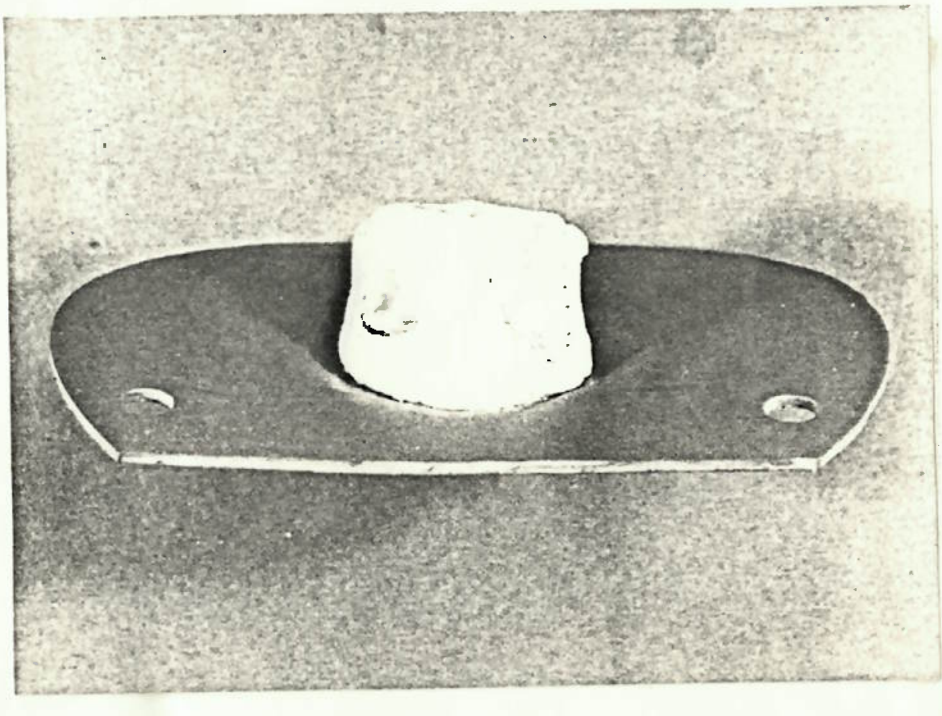


Figura 5 - Válvula de Duramáter (presa numa placa para ensaio).

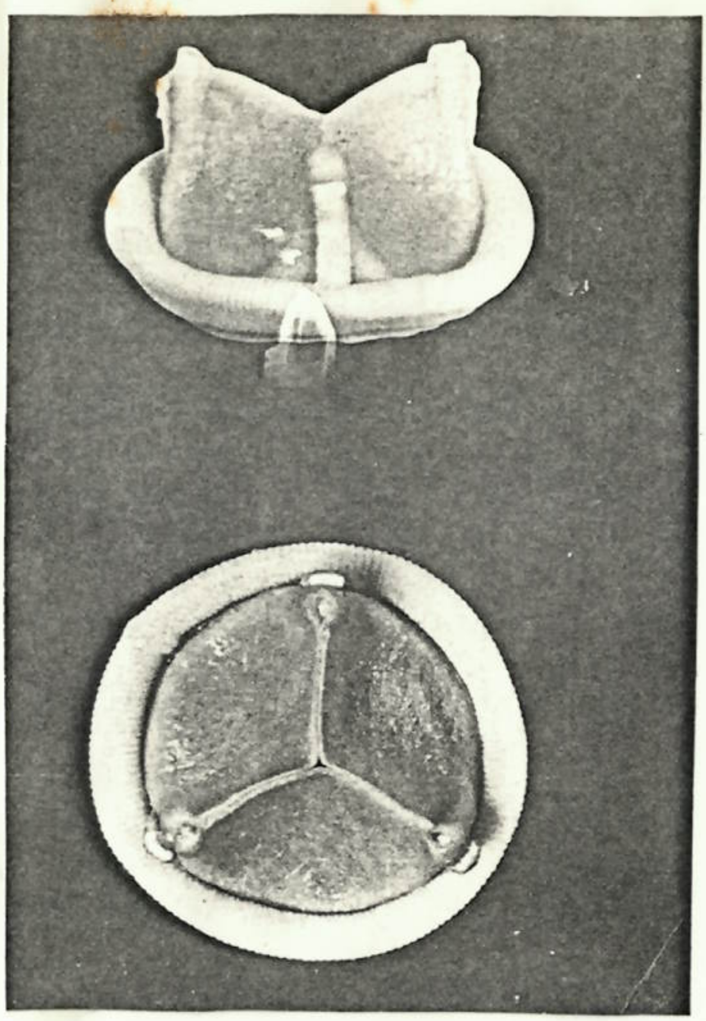


Figura 6 - Válvula "Ionescu-Shiley" (pericárdio bovino).

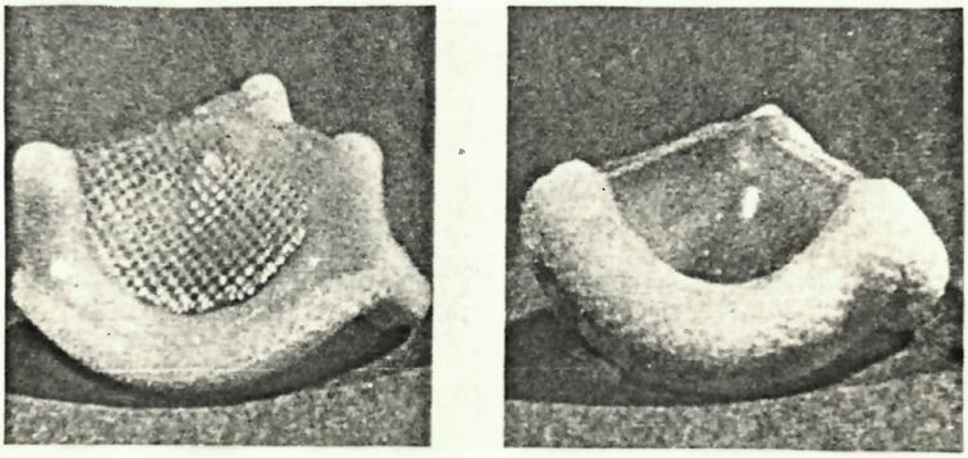


Figura 7 - Válvula de "Dracon" (impregnada com silicone)

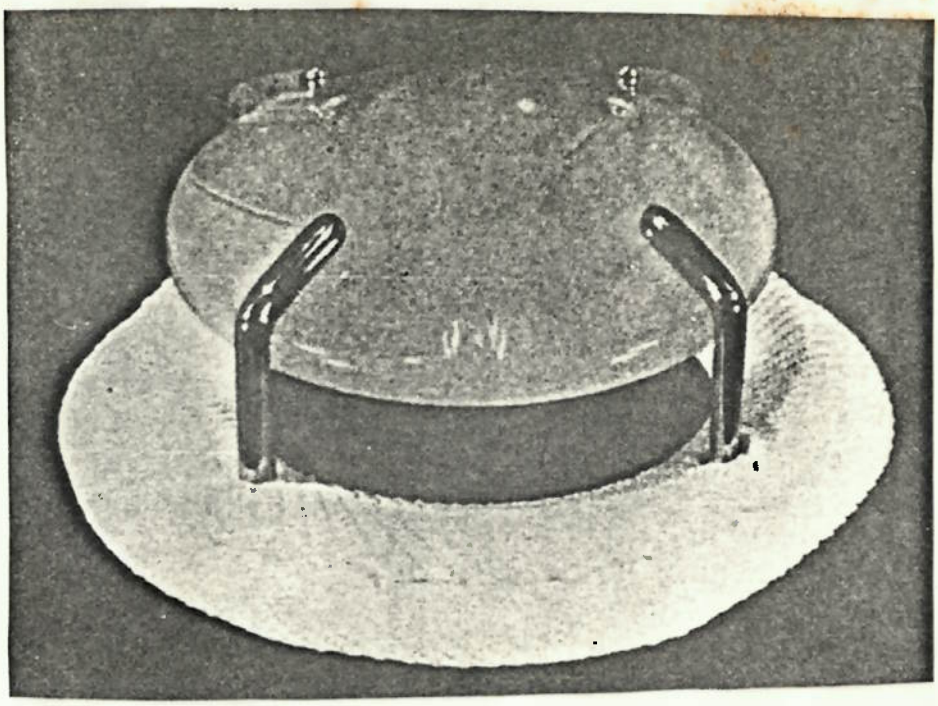


Figura 8 - Válvula "Cooley-Cutter".

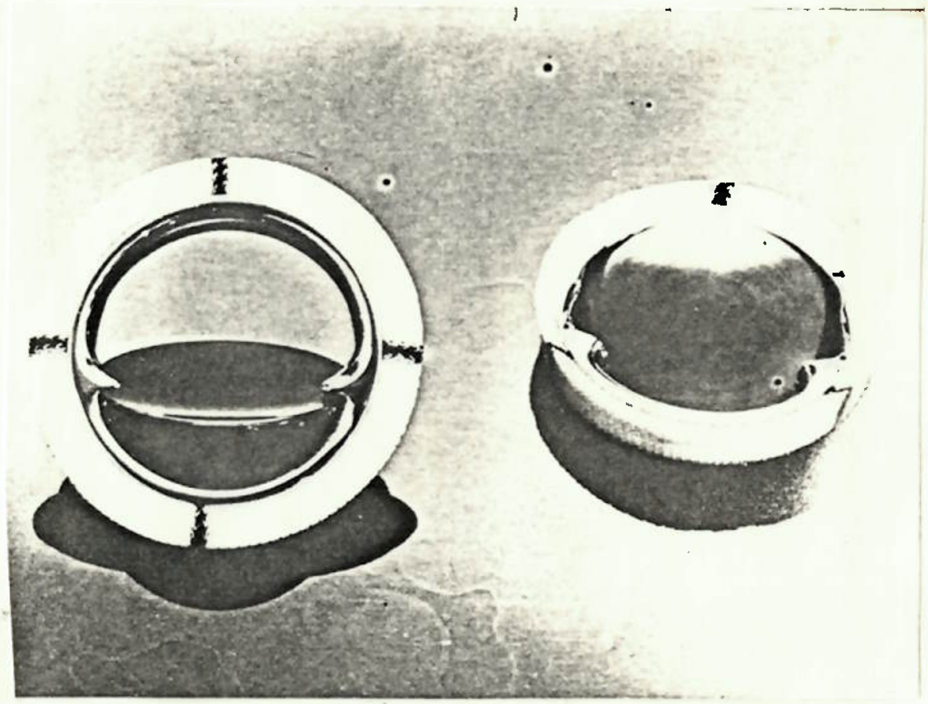


Figura 9 - Válvula "Omni-Carbon".

8. Deve ser capaz de ter fixação permanente;
9. Não deve incomodar o paciente;
10. Deve ser tecnicamente prática para implantar.

Mas, atualmente, não existe uma prótese valvar capaz de satisfazer todos esses requisitos.

Apesar do grande desenvolvimento das próteses valvares durante os últimos 40 anos, elas possuem muitos problemas pós-operatórios e de desempenho.

Os problemas mais comuns são:

1. Formação de trombos (coagulação) e crescimento de tecidos;
2. Tromboembolismo (embolia com trombo);
3. Má fixação;
4. Deslocamento da válvula;
5. Regurgitação;
6. Infecção;
7. Hemólise (destruição dos glóbulos vermelhos);
8. Falha mecânica;
9. Distúrbio do ritmo cardíaco;
10. Complicações devido ao uso de anti-coagulante;
11. Perturbações no miocárdio.

Dentre todos, o problema mais sério é o tromboembolismo que traz complicações pós-operatórias podendo causar deficiência física ou até a morte.

Observou-se que as próteses valvares são pontos de formação de trombos devido às seguintes causas:

a) Os trombos podem surgir em regiões de estagnação na válvula;
b) A forma do obstáculo ao fluxo (bola, disco, etc.) exerce influência na formação de trombos à jusante da válvula;
c) O tipo de material empregado na válvula estimula o crescimento de trombos.

Os trombos (coágulo) ao crescer, começam a obstruir o fluxo sanguíneo (estenose) e, se o coágulo começar a se soltar da válvula cardíaca artificial, poderá se alojar mais a jusante quando o diâmetro do vaso sanguíneo se tornar menor que o coágulo (embolia), podendo causar vários problemas fisiológicos.

Uma forma de atenuar a formação de trombos é a utilização de anti-coagulante (terapia utilizada em todos os portadores de próteses rígidas tipo bola, disco, etc.); mas a utilização de anti-coagulante torna o organismo suscetível à hemorragia.

A hemólise é um outro problema da válvula relacionado com o escoamento do sangue. A hemólise é a danificação dos glóbulos vermelhos do sangue. Ela ocorre devido a efeitos de pressão e efeitos de tensão de cisalhamento.

II.3 - DINÂMICA DO ESCOAMENTO DA PRÓTESE VALVAR

Como se pode notar, é imprescindível a determinação do comportamento dinâmico do escoamento através da prótese valvar. Dessa forma, podemos avaliar se as características hidrodinâmicas de determinada válvula são fisiologicamente aceitáveis. O escoamento através da prótese deve ser suave, com um mínimo de turbulência, sem tensões elevadas (viscosas) e choques, não deve ter região de estagnação do escoamento na prótese, deve ter mínima variação de pressão através da prótese, enfim, não deve traumatizar os componentes celulares do sangue.

Devido à importância do conhecimento da performance da prótese valvar, vários ensaios "in vitro" têm sido realizados tanto em regime permanente como em regime pulsátil.

Vieira "et alli", fizeram um dispositivo simples para estudo da perda de carga da válvula de duramáter através de um escoamento permanente (figura 12).

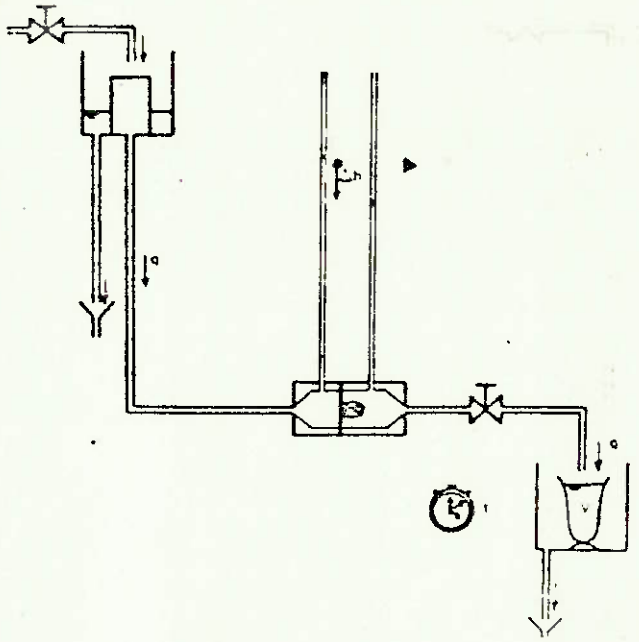


Figura 12 - Dispositivo para estudo da perda de carga da válvula de duramáter.

Yoganathan, Shoenberg, Bellhouse, e outros desenvolveram aparelhos e dispositivos de fluxo contínuo para estudo de escoamento através de próteses valvares.

De forma análoga, vários ensaios em regime pulsátil foram propostos. Estes ensaios basicamente simulam o funcionamento do lado esquerdo do coração.

CAPÍTULO III

III - DESENVOLVIMENTO DO PROTÓTIPO

III.1 - CONSIDERAÇÕES GERAIS

O dispositivo proposto tem circuito aberto, e utiliza como fluido de trabalho o ar atmosférico que é impulsionado por um ventilador em direção à seção de ensaio com a prótese fixa. Em seguida o ar é eliminado ao meio ambiente (figura 13).

Figura 13 - Desenho Esquemático do circuito.

A técnica de visualização consiste na adição no ar ventilado de gotículas de água.

III.2 - COMPONENTES E SUB-CONJUNTOS DO PROTÓTIPO

A) VENTILADOR:

Motor - corrente contínua

12 V $rpm_{máx} = 2600$ rpm

B) BOCAL DE ENTRADA: (Desenho 2)*

Material: Policarbonato

Processo de conformação: "Vacuum-forming"

Tem a função de dirigir o ar do ventilador ao duto intermediário .

C) DUTO INTERMEDIÁRIO:

Material: PVC

Tem a função de diminuir a turbulência do ar proveniente do ventilador.

D) SEÇÃO DE ENSAIO:

Para permitir a visualização nítida do escoamento através da prótese valvar, na região da prótese a parede da tubulação deve ser de material transparente.

Foi então, escolhido o acrílico como material para os dutos da seção de ensaio pela sua usinabilidade e sua excelente visibilidade. Além disso, o acrílico já é vendido em tubos de diversos diâmetros, em lojas especializadas sendo seu custo viável financeiramente.

Para as contrações e expansões da seção de ensaio foi escolhido o policarbonato que apesar de seu custo elevado, é muito utilizado na Divisão de Bio-engenharia sendo fácil de ser conformado através de "Vacuum-forming", além

* Os desenhos encontram-se no Apendice.

de obter um bom acabamento.

No processo de "Vacuum-forming" é necessário inicialmente tirar a umidade da placa (de policarbonato) a ser conformada.

Para tanto, deve-se colocar a placa em estufa a uma temperatura de 120ºC durante pelo menos 6 horas.

Se a umidade da placa não for retirada, no processo de conformação aparecerão bolhas no conformado.

A seção de ensaio pode ser dividida em:

D.1 - <u>Duto de Entrada</u>
Material: Acrílico

D.2 - <u>Contração de Entrada</u> (Desenho 3)
Material: Policarbonato
Processo de conformação: "Vacuum-forming"

D.3 - <u>Expansão de Saída</u> (Desenho 4)
Material: Policarbonato
Processo de conformação: "Vacuum-forming"

D.4 - <u>Duto de Saída</u>
Material: Acrílico

E) <u>TUBOS DIRECIONADORES</u>

À montante da seção de testes temos um conjunto de tubos direcionadores ("Honey-comb") que têm a função de reduzir as componentes laterais da velocidade média e das maiores turbulências. Esses tubos direcionadores, naturalmente, produzem alguma turbulência, com turbilhões da mesma ordem de grandeza que o diâmetro dos tubos.

De acordo com "FLUID METERS", é recomendável que o tubo direcionador tenha comprimento de L=2D (D = diâmetro da seção).

Material: Polipropileno

Diâmetro Externo do Tubo: 6mm

Diâmetro Interno do Tubo: 5mm

Comprimento: 21 cm

F) DISPOSITIVO PARA VISUALIZAÇÃO DO ESCOAMENTO

O dispositivo , de concepção simples, consiste de um recipiente no interior do qual é colocado gelo seco (CO_2) juntamente com água. O gelo seco ao entrar em contato com a água sofre sublimação e condensa o vapor do ar , produzindo gotículas de água. As gotículas de água são dirigidas ao duto intermediário, à montante dos tubos direcionadores por meio de quatro tubos de latex que saem da tampa do recipiente.

Observa-se que a pressão gerada pela sublimação do gelo seco no interior do recipiente, é suficiente para enviár as gotículas ao duto intermediário.

Iluminando-se intensamente a região a ser observada , as gotículas de água indicam a configuração do escoamento.

Tem-se vantagem em confinar a iluminação em uma seção do escoamento para visualização. Consegue-se isso, através de Slides inteiramente escuros com uma fina faixa transparente no centro.(figura 14).

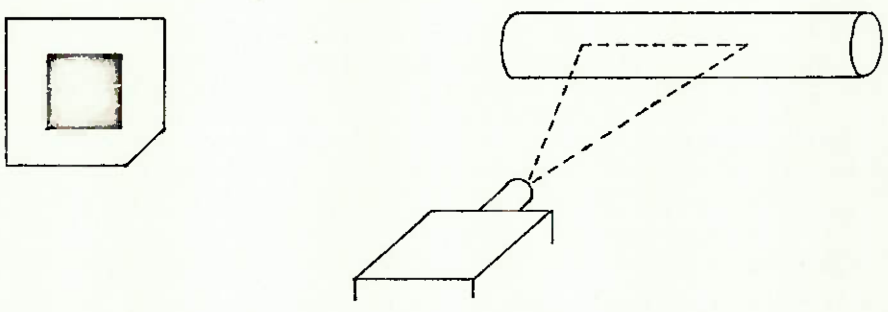


Figura 14 - Iluminação em um único plano.

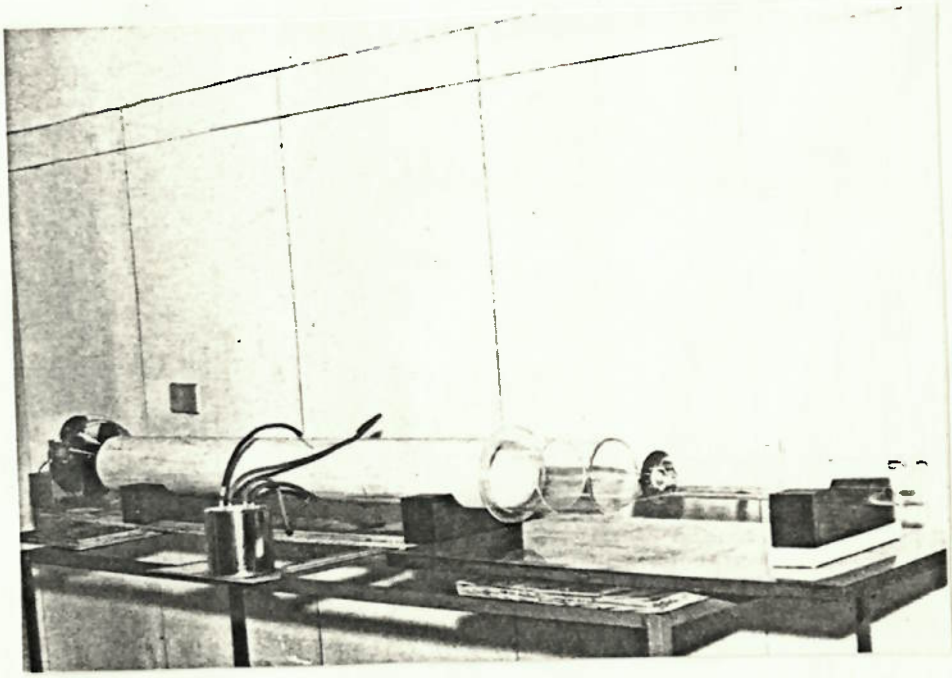


Figura 15 - Vista completa do dispositivo.

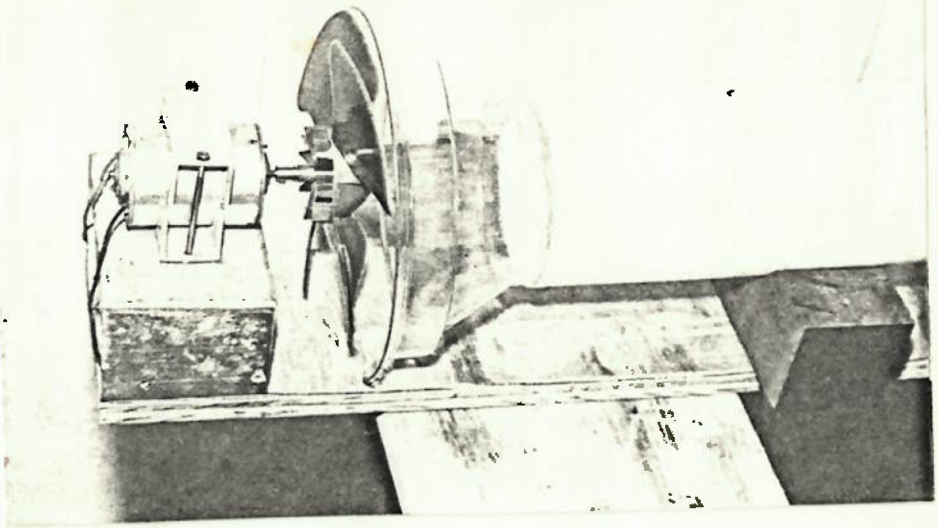


Figura 16 - Detalhe do Ventilador.

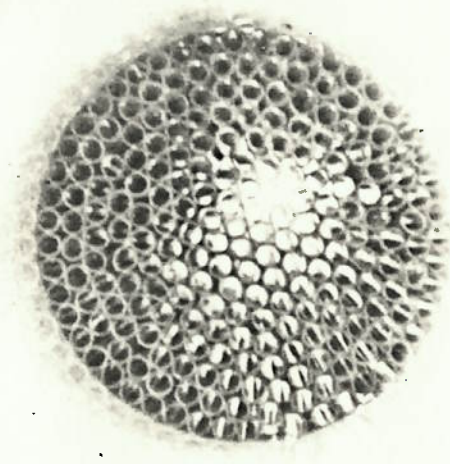


Figura 17 - Vista dos tubos direcionadores.

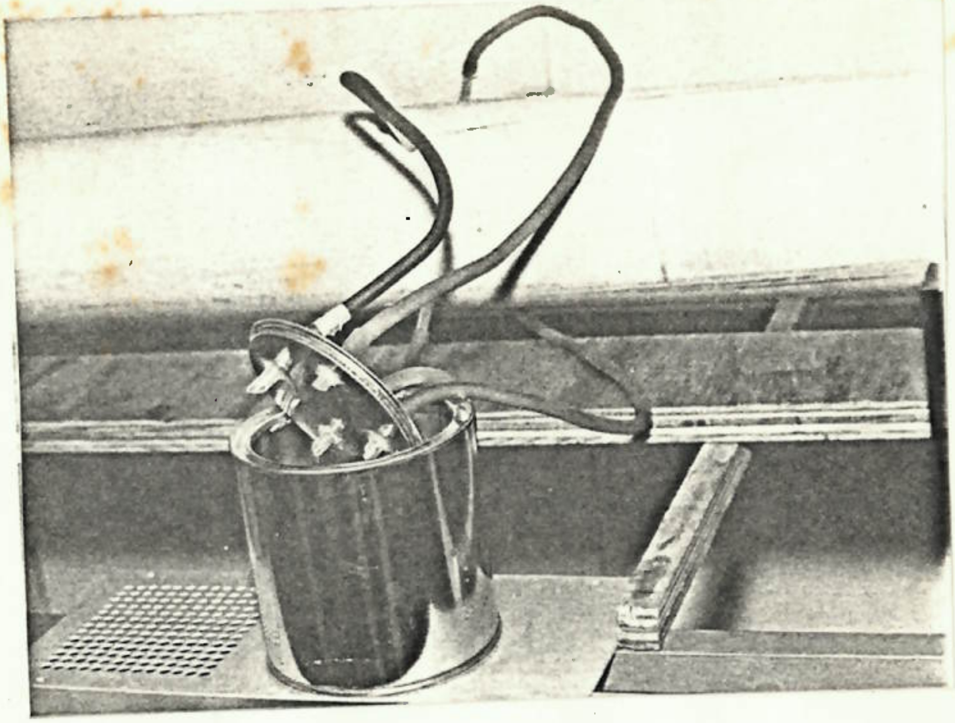


Figura 18 - Detalhe do recipiente de gelo seco.

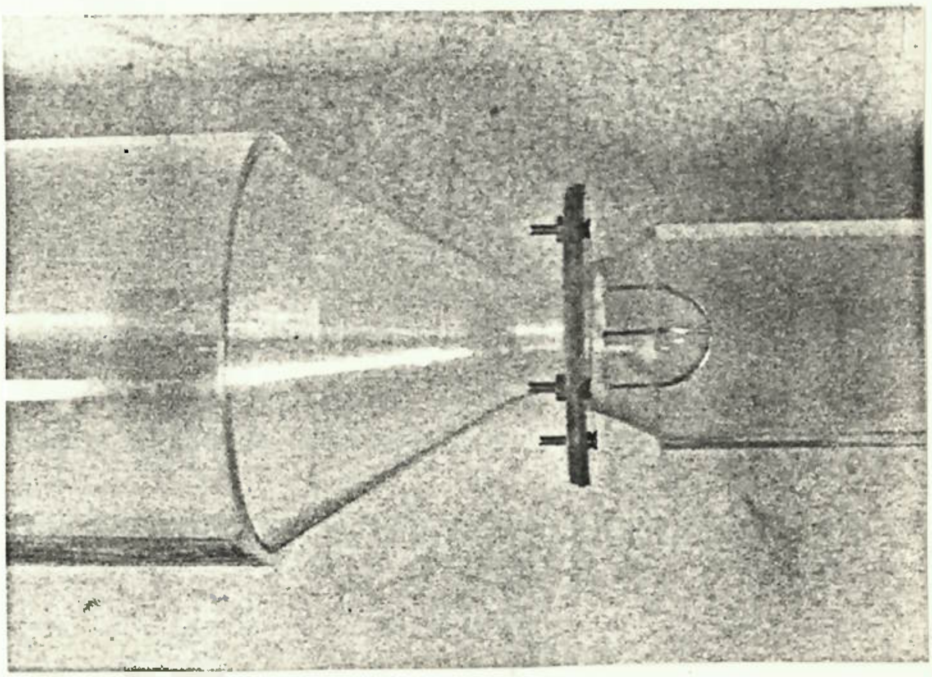


Figura 19 - Detalhe da seção de ensaio.

CAPÍTULO IV

IV - CARACTERÍSTICAS DO CIRCUITO

IV.1 - DETERMINAÇÃO DA VAZÃO

Para determinação da vazão é utilizado o fluxômetro que consiste de um tubo com uma hélice no interior que gira com o passar do fluido cuja vazão se deseja determinar (figura 20).

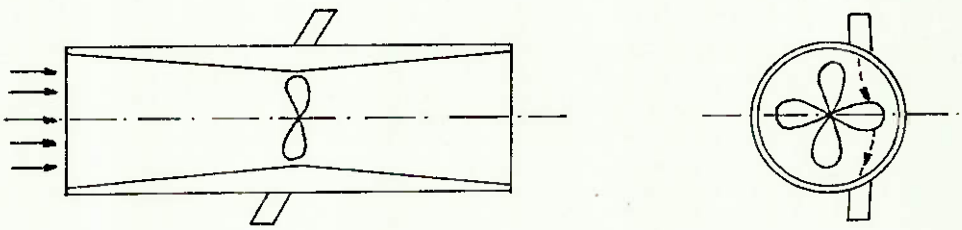


Figura 20 - Desenho esquemático do fluxômetro.

Na região da hélice estão colocados no sentido radial, um foto emissor e um foto transistor receptor de um "link" de luz que é interrompido com o passar das pás da hélice.

Estes sinais são transformados em tensão que podem ser lidas por um multímetro, ou então a frequência destes sinais pode ser observada na tela de um osciloscópio.

Quanto maior a vazão, maior será a rotação da hélice, e consequentemente terá um sinal maior, com maior frequência.

O aparelho foi dimensionado para operar numa faixa de 2 a 150 rps ou seja, para a deteção de 8 a 600 pulsos por segundo; mas, foi instalado um flip-flop na entrada que permite que essa variação seja dobrada.

Para calibração do fluxômetro faz-se passar uma vazão conhecida no fluxômetro e mede-se a tensão correspondente.

Observa-se que para baixas velocidades o fluxômetro não tem muita precisão devido ao fato de que as forças de atrito começam a ser significantes.

No gráfico 1 está a curva de calibração do fluxômetro utilizado para o ar, determinada experimentalmente. Ele foi obtido conhecendo-se somente três pontos e sabendo-se que a tensão (V) varia linearmente com a vazão (Q).

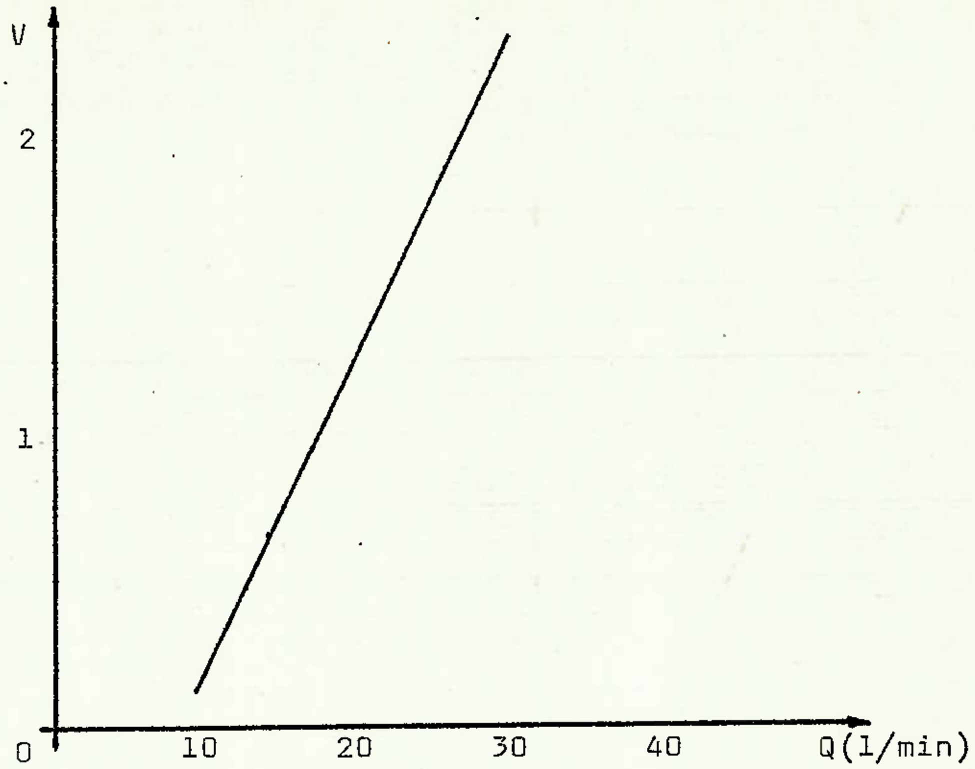


Gráfico 1 - Curva de calibração do fluxômetro.

IV.2 - DETERMINAÇÃO DA CURVA DO IMPULSOR

Com auxílio de um tacômetro, mede-se a rotação da hélice, para a tensão de entrada variando de 0 a 12 Volts.

A máxima rotação atingida pelo impulsor na tensão de 12 V é de 2600 rpm.

No gráfico 2 (rpmxV), é dada a curva do impulsor.

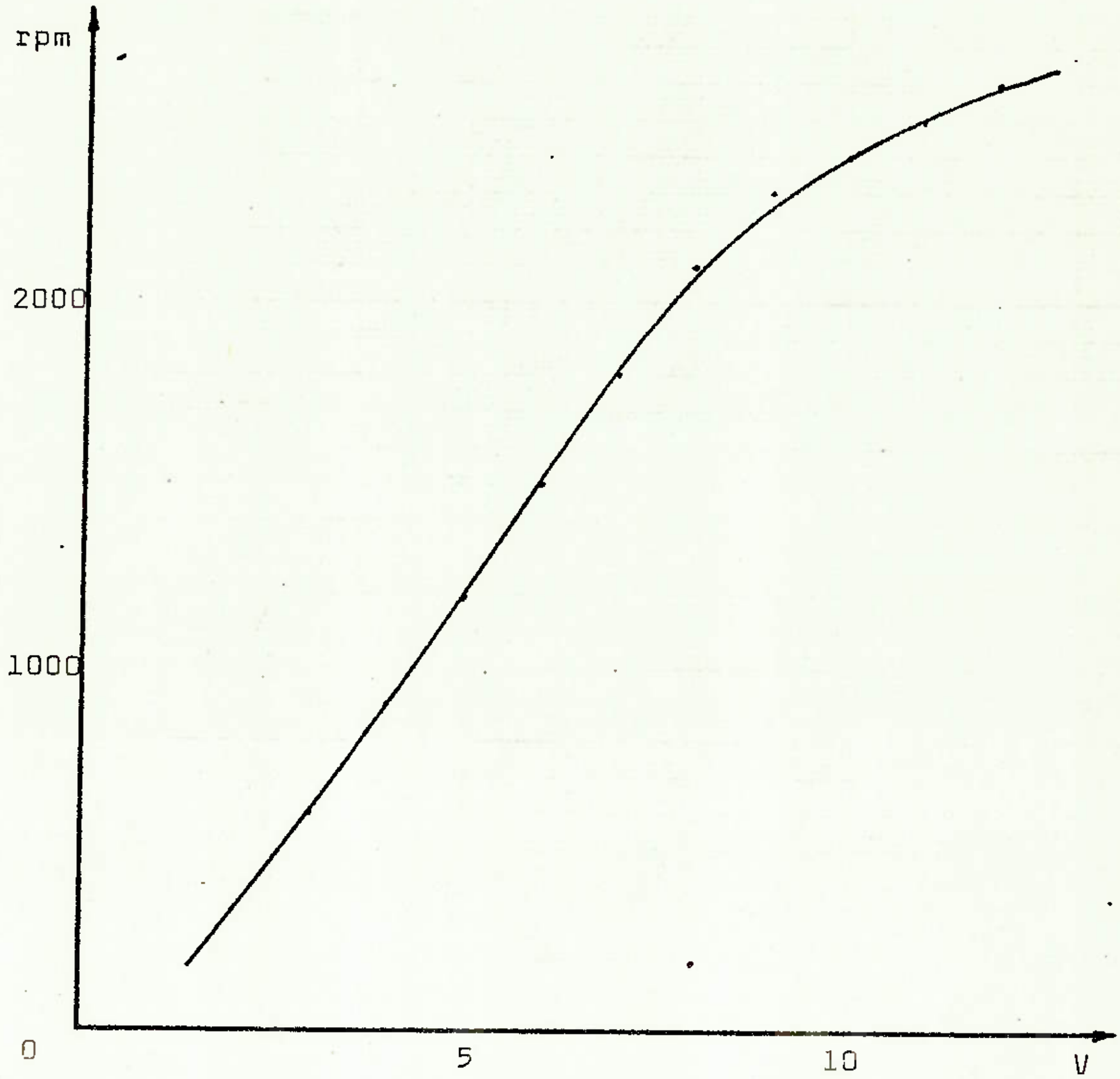


Gráfico 2 - Curva do impulsor.

IV.3 - DETERMINAÇÃO DA CURVA CARACTERÍSTICA DO PROTÓTIPO

Variando-se a tensão de entrada do impulsor, ou seja, variando-se a sua rotação, obtemos a leitura correspondente do fluxômetro colocado à jusante da seção de ensaio, no saída do dispositivo.

Com isto, levantamos a tabela abaixo e construímos o gráfico Q x rpm (Gráfico 3).

Q (l/min)	RPM
18,24	330
46,62	600
75,00	900
95,27	1200
117,57	1500
139,90	1800
160,14	2100
178,40	2300
188,50	2400

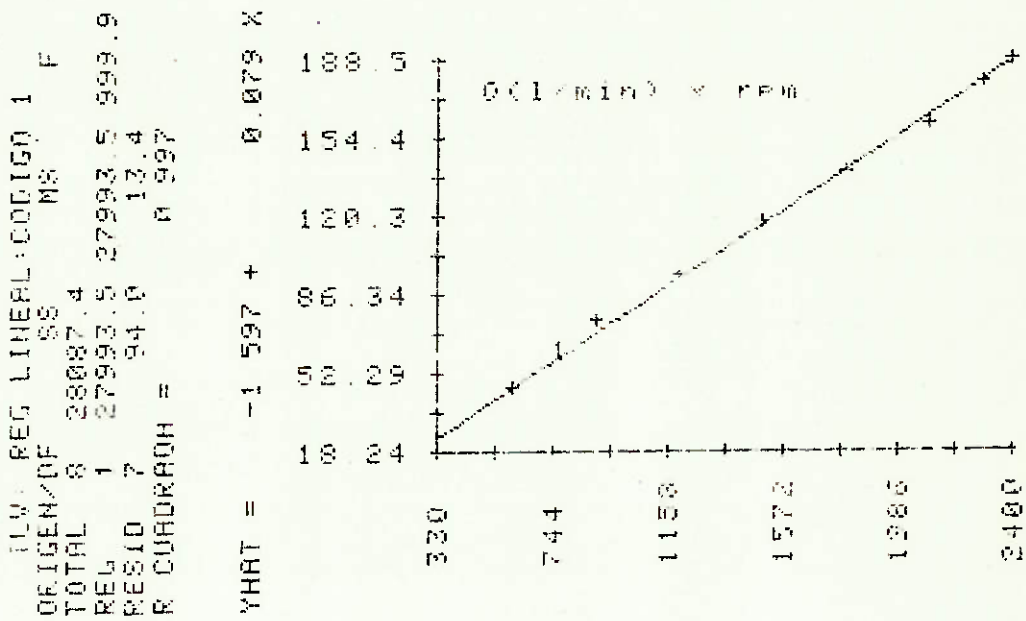


Gráfico 3 - Curva do protótipo.

CAPÍTULO V

V - RESULTADOS

V.I - COMPORTAMENTO DO ESCOAMENTO

Observou-se que até a vazão de Q = 24 l/min, o escoamento na tubulação à montante da contração da seção de ensaio é laminar. A partir dessa vazão, o escoamento se torna turbulento.

Assim, para esta vazão, à montante da seção de ensaio, temos:

$D = 10{,}5\ cm = 0{,}105\ m$ (Diâmetro da tubulação)

$S = \frac{\pi . D^2}{4}$ $\qquad S = 8{,}70 . 10^{-3}\ m^2$

$Q = 24\ l/min = 0{,}4 . 10^{-3}\ m^3/s$

$Q = V.S$ $\qquad V = \frac{Q}{S}$ (V= velocidade média de escoamento na seção considerada)

Logo:
$V = 0{,}05\ m/s$

Tomando $\nu = 15{,}1.10^{-6}\ m^2/s$ (ν = viscosidade cinemática a 20ºC e Pressão Atmosférica)

$Re = \frac{V.D}{\nu}$ $Re = \frac{0{,}05.0{,}105}{15{,}1.10^{-6}}$

Logo:
$Re = 348$ Regime Laminar

Nestas condições, o escoamento na seção de ensaio é visível, possibilitando observar as turbulências causadas pela prótese valvar. A partir dessa vazão, torna-se difícil visualizar o escoamento.

Assim, para esta vazão na seção de ensaio, temos:

$S = \frac{\pi D^2}{4}$

$D = 2{,}5\ cm = 0{,}025\ m$

$S = \frac{\pi .0{,}025^2}{4}$ $S = 4{,}91.10^{-4}\ m^2$

$Q = 0{,}4.10^{-3}\ m^3/s$

$V = \frac{Q}{S}$

Logo:
$V = 0{,}81\ m/s$

Tomando $\nu = 15{,}1.10^{-6}\ m^2/s$ (ν = viscosidade cinemática t=20ºC e P=1atm)

$Re = \frac{V.D}{\nu}$ $Re = \frac{0{,}81.0{,}025}{15{,}1.10^{-6}}$

Logo:

$Re = 1350$

V.II - ANÁLISE DA COMPRESSIBILIDADE

Sabe-se que para baixos números de Mach, a densidade varia muito pouco, e que para altos números de Mach a densidade varia rapidamente até um certo limite.

Então, para $M < 0{,}3$ podemos considerar o escoamento incompressível.

Calculando-se o número de Mach na garganta da seção de ensaio, nas condições ideais de operação do dispositivo (Q = 24 l/min), temos:

$M = \frac{V}{a}$

$V = 0{,}81$ m/s

$a = \sqrt{k.R.T}$

k = 1,4 (constante adiabática)

R = 287 Nm/kg K (constante do gás)

T = 20 + 273 T = 293º K (temperatura ambiente)

Logo:

$a = 343{,}11$ m/s

$M = \frac{V}{a}$ $M = \frac{0{,}81}{343{,}11}$

Obtemos:

$\dot{M} = 0,0024$

Nota-se, então, que o escoamento em todo o dispositivo ocorre em regime subsônico e incompressível, e a maior velocidade ocorre na garganta da seção de testes.

A contração da seção de ensaio se comporta como um bocal e a expansão, como um difusor. O bocal converte energia de pressão em energia cinética e o difusor, energia cinética em energia de pressão. Dessa forma, a seção com menor diâmetro apresentará maior velocidade.

V.III - ENSAIO DA PRÓTESE DE "STARR-EDWARDS"

Para ensaios iniciais foi utilizada a válvula de "Starr-Edwards".

Ela foi adaptada em um disco de borracha e este foi preso na seção de ensaio por meio de quatro parafusos. Para manter a válvula permanentemente aberta, a bola de silicone foi colada na gaiola utilizando-se cola de silicone.

Observando-se o escoamento, constatou-se que esta prótese não é recomendável para utilização no organismo.

Ela oferece resistência ao fluxo fisiológico, causa grande turbulência à jusante do escoamento (formação de vórtices) e, ainda possui regiões de estagnação do escoamento na extremidade da prótese (fim de curso da bola).

Logo, ela provoca a formação de trombos e a danificação dos glóbulos vermelhos (hemólise).

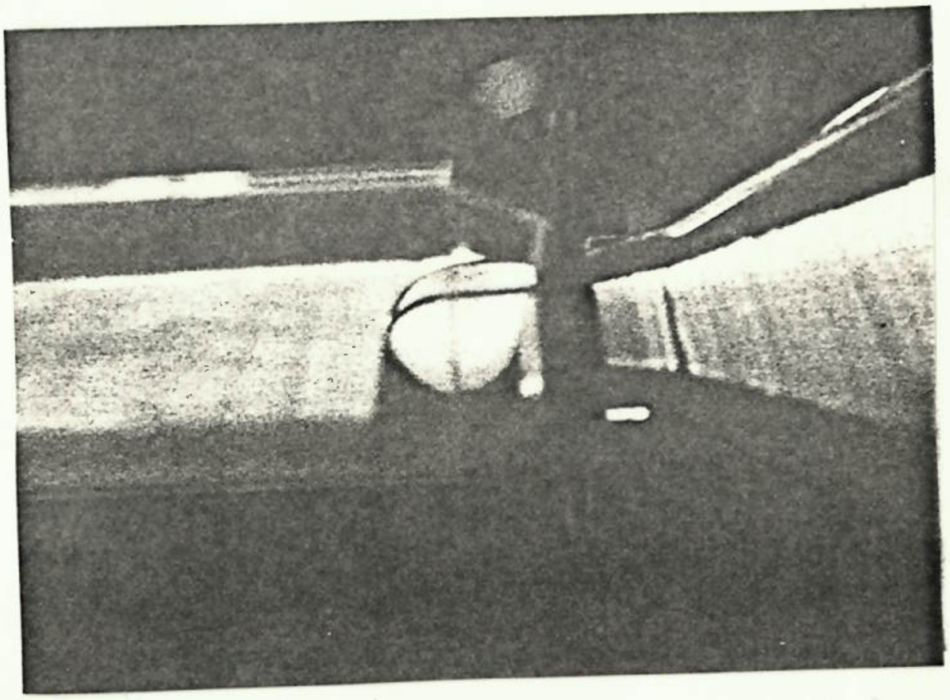


Figura 21 - Ensaio em válvula de "Starr-Edwards".

CAPÍTULO VI

VI - COMENTÁRIOS

VI.1 - MELHORAMENTOS DO ESCOAMENTO

O dispositivo proposto tem seu desempenho ótimo (boa visualização) com Re = 1350, abaixo do número de Reynolds fisiológico de pico (Re = 8000). Este fato é considerável se for determinar a tensão de cisalhamento devido à turbulência, a tensão de cisalhamento devido à viscosidade ou a força de arrasto na prótese nas condições mais críticas.

Para melhorar o desempenho do dispositivo, posteriormente serão instaladas uma ou mais telas metálicas à montante da seção de testes. Elas reduzem as componentes longitudinais de turbulência e da variação da velocidade média numa extensão bem maior do que as componentes laterais (que são reduzidas pelos tubos direcionadores).

VI.2 - CONSIDERAÇÕES NA DINÂMICA DO ESCOAMENTO

Nos ensaios realizados, só podemos retirar resultados qualitativos do escoamento, pois, não dispomos de meios pará avaliar a velocidade pontual em cada trecho da prótese.

O tubo de Pitot é um dos métodos mais precisos para determinação da velocidade, mas só apresenta bons resultados em correntes de velocidades maiores.

O anemômetro de fio quente é mais utilizado para gases do que para líquidos, pois, a água a ser medida deve ser extremamente pura, para nao ter condutibilidade suficiente para interferir na operação da sonda. Ainda, existem dificuldades com partículas que se depositam sobre as sondas, provocando erosão da película protetora e quebra do fio, além de alterar a sua aferição.

O método fotográfico consiste em filmar a região do escoamento com uma câmara fotográfica de alta velocidade , ou fotografar a região do escoamento com fotografia de alta sensibilidade. Esse método, até então não apresentou resultados satisfatórios.

O método mais recomendável para o dispositivo é o Anemômetro Laser Doppler. Ele é baseado no efeito Doppler utilizando uma fonte de luz coerente (Laser). Esse método nao interfere no escoamento do fluido apresentando excelentes resultados. Porém, seu custo é elevado e de concepção muito complexa.

No apêndice encontra-se o catálogo de um Anemômetro Laser Doppler fabricado pela "DISA ELEKTRONIK A/S" (Dinamarca). Ele consegue detectar velocidades de até 2mm/s.

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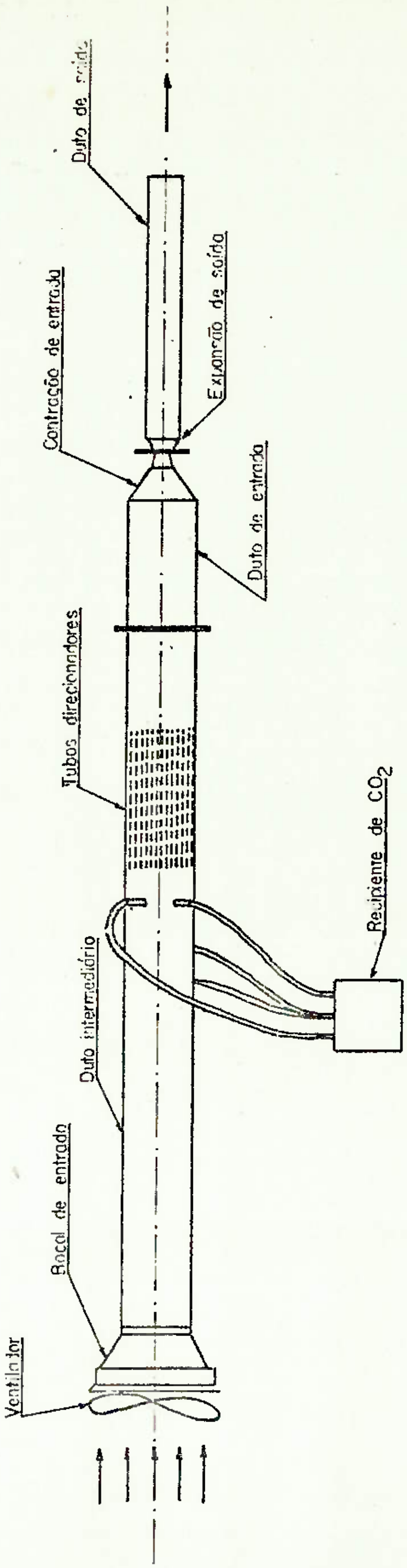
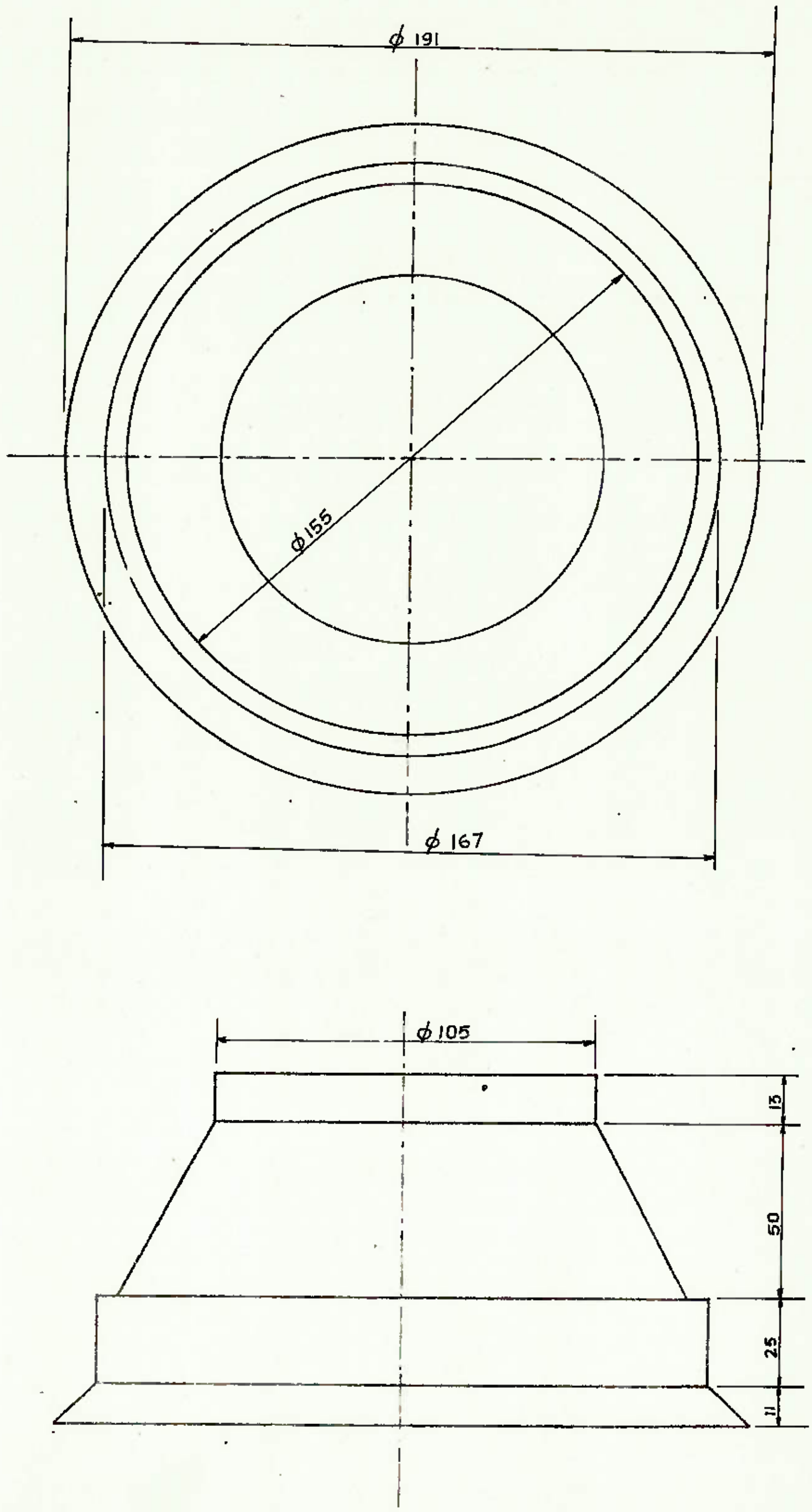
APÊNDICES

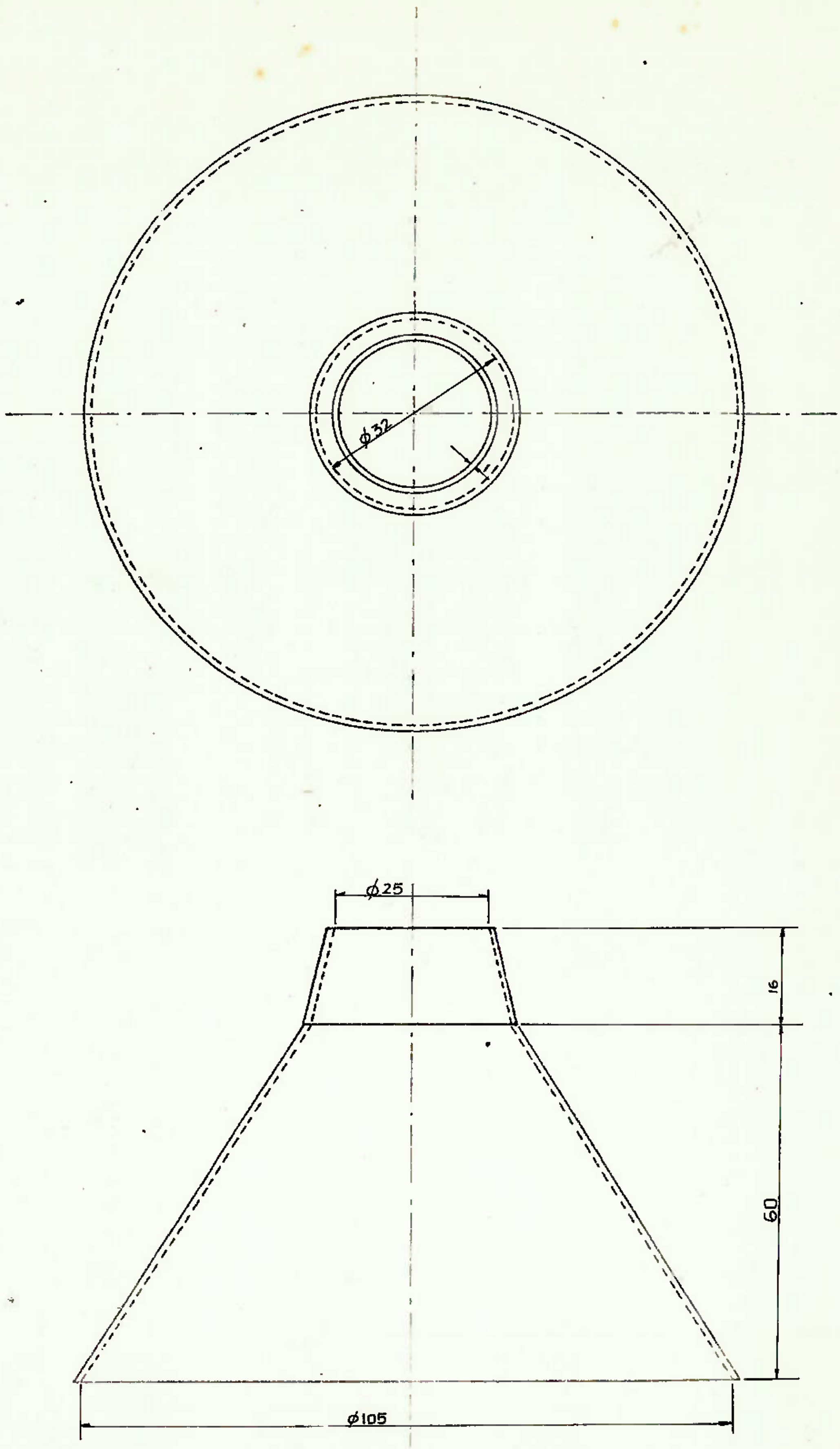
APÊNDICE - A



EPUSP	DISPOSITIVO PROPOSTO	ESCALA 1:10
		22/11/82
5º ANO		DES. 01

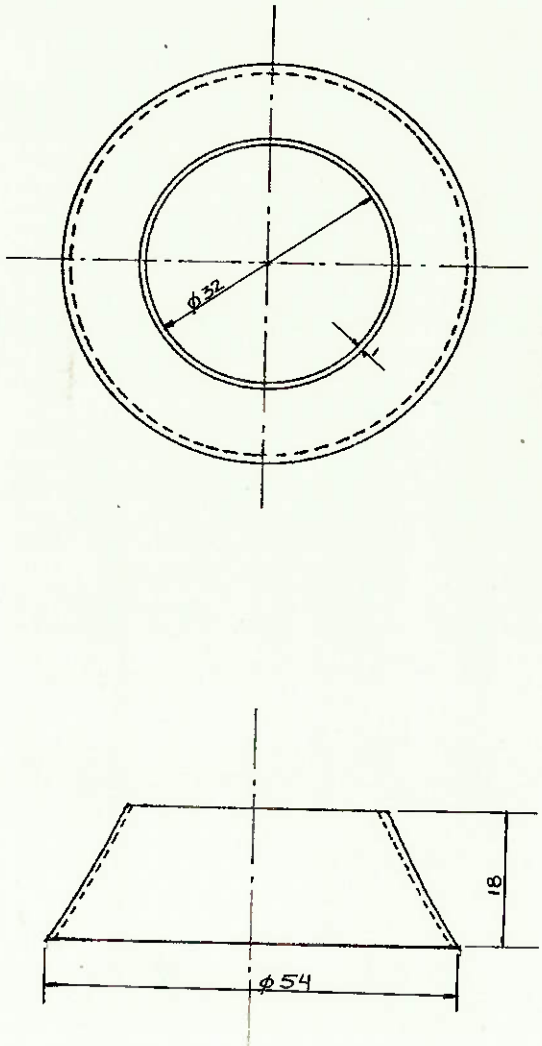


EPUSP	BOCAL DE ENTRADA	ESCALA 1:2
		22/11/82
5º ANO		DES. 02



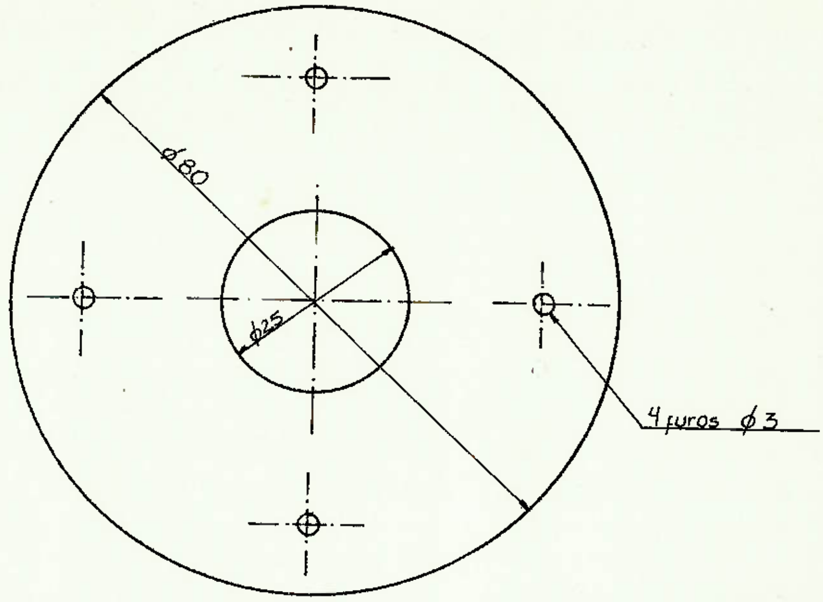
medidas em mm

EPUSP	CONTRAÇÃO DE ENTRADA	ESCALA 1:1
		22/11/82
5º ANO		DES. 03

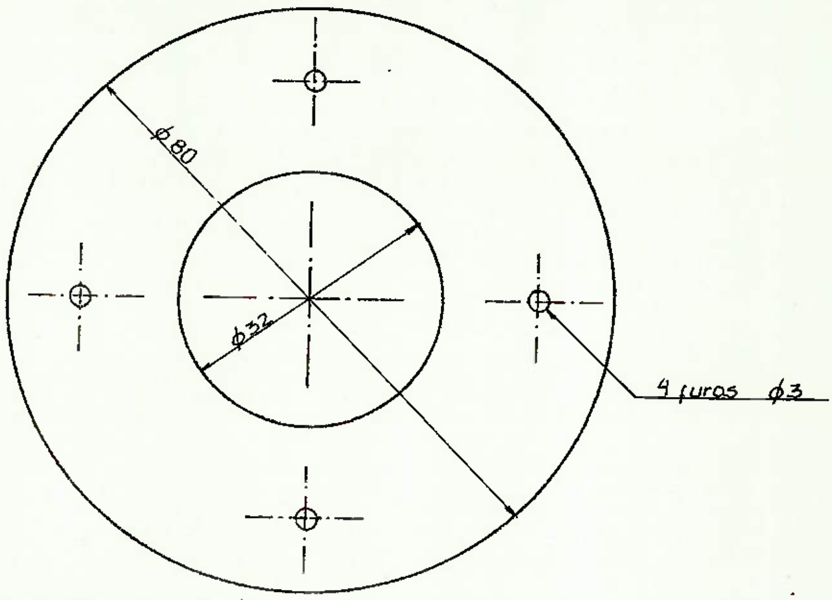


medidas em mm

EPUSP	EXPANSÃO DE SAIDA	ESCALA 1:1
		22/11/82
5º ANO		DES. 04



FLANGE DE ENTRADA



FLANGE DE SAÍDA

Material: Policarbonato

medidas em mm

Espessura 1 mm

EPUSP	FLANGES DA SEÇÃO DE ENSAIO	ESCALA 1:1
		22/11/82
5º ANO		DES. 05

APÊNDICE - B

Laser Doppler Anemometry Equipment Catalog

DISA

Contents | Page

LDA

14-5-80
3/5

Jsing LDA in Flow Measurements

Introduction

In many cases, a flow can only be measured correctly if a non-contact sensor is used. For example, a flow pattern may be of so small dimensions that even the smallest of probes would affect the parameters under investigation, and a flow of a chemically active medium would damage a physical probe. Some flows even make the physical presence of a probe impossible; cases in point are flows around propellors, flows in turbines, etc.
In such flows Laser Doppler Anemometry (LDA) may be the only possible means of measuring local flow velocity, and in many other flows LDA may be the most practical method of investigating the dynamic properties of flows.

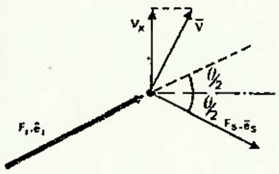


Fig. 1. Vectors in LDA

LDA Theory
The Laser Doppler Anemometer uses the Doppler shift (Christian Doppler, 1842) of light scattered by moving particles to determine particle velocity and thus find the fluid flow velocity. The general equation expressing the Doppler shift (f_D) in the frequency of the scattered light as a function of particle velocity $\bar{V}$ is:

$$f_D = f_s - f_i = \frac{1}{\lambda} \cdot \bar{V} \cdot (\hat{e}_s - \hat{e}_i)$$

f_s, frequency of scattered light
f_i, frequency of incident light
$\hat{e}_s$, $\hat{e}_i$ unity vectors of scattered and incident respectively and
λ, wavelength of incident light

The use of a monochromatic coherent light source such as a laser beam makes it possible to determine the values of f_i and λ. $\hat{e}_s$, $\hat{e}_i$ depend on the geometry of the system. The velocity component V_x measured by LDA will be in the plane formed by $\hat{e}_i$ and $\hat{e}_s$ and perpendicular to the line bisecting the angle formed by the two unity vectors (Fig 1).

LDA Modes
Three modes of operation - the Reference Beam Mode, the Differential Doppler Mode, and the Dual Scatter Mode - have been used in Laser Doppler Anemometry, but only the first two have found general acceptance.

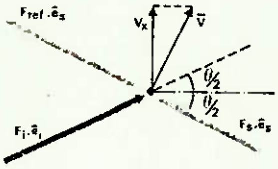


Fig. 2. Reference Beam Mode

Reference Beam Mode. This mode was used by YEH and CUMMINGS in their original article in Applied Physics, 1964, in which LDA was first presented. In the Reference Beam Mode light scattered from one laser beam mixes in the photodetector with light from a reference beam. In practice this is done by a coaxial superposition by means of beam splitters and mirrors of the scattered beam and the reference beam at the photodetector (Fig.2). The reference beam impinges constantly on the photodetector, and best S/N ratio will be obtained at high particle densities.
Typical signal characteristics are: Continuous modulation with coherent parts separated only by amplitude dropouts at phase shifts, good-to-moderate S/N ratio at high particle densities (water flows), and poor S/N ratio at low particle densities (air flows).
Since the equation for f_D includes the unity vector $\hat{e}_s$ for scattered light, the photodetector must have a small collecting aperture and be placed coaxially with the reference beam.

Differential Doppler Mode (Fig. 3). This mode uses two beams of equal intensity as scattering beams. For any direction of detection the light picked up by the photodetector will consist of the superposition of light scattered from either beam. f_D can be found as the difference between the two scattering frequencies f_{s1} and f_{s2}, and it can be seen that f_D is independent of direction of scattering $\hat{e}_s$. Because of the independence of the positioning of the receiving optics, the Differential Doppler Mode can be used both in forward scatter and in backscatter, making it possible to adapt the LDA system to different configurations. It can also be used with a large receiving aperture, enabling measurement on small single particles.

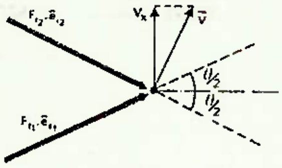


Fig. 3. Differential Doppler Mode

Typical signal characteristics are: Good S/N ratio from single particles with low noise level between bursts (noise proportional to light level on photodetector), good-to-moderate S/N ratio on flows of high particle density (air or water), poor S/N ratio on flows having high density of very small particles (typically, polluted water flow).

Fringe Model. The Differential Doppler Mode can be explained more directly by means of a

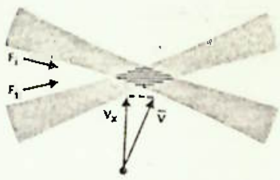


Fig. 4. Fringe Model

Fringe Model (Fig. 4). At the beam crossing, the two laser beams can be described as two beams of monochromatic coherent light, each with plane and parallel wave fronts. In the intersection, alternately constructive and destructive superposition of the two beams will form a fringe pattern of planes having a strong electromagnetic field separated by planes having a weak electromagnetic field. Distance between fringes, d_f, can be calculated from the angle of intersection θ and wavelength λ_c of the laser light.

$$d_f = \frac{\lambda_c}{2 \sin \theta/2}$$

A particle moving across the fringe pattern with a velocity component V_x, perpendicular to the fringe planes will scatter light at a frequency f_d.

$$f_d = \frac{V_x}{d_f} = V_x \cdot \frac{\hat{e}}{2 \sin \theta/2}$$

55X Modular LDA Optics

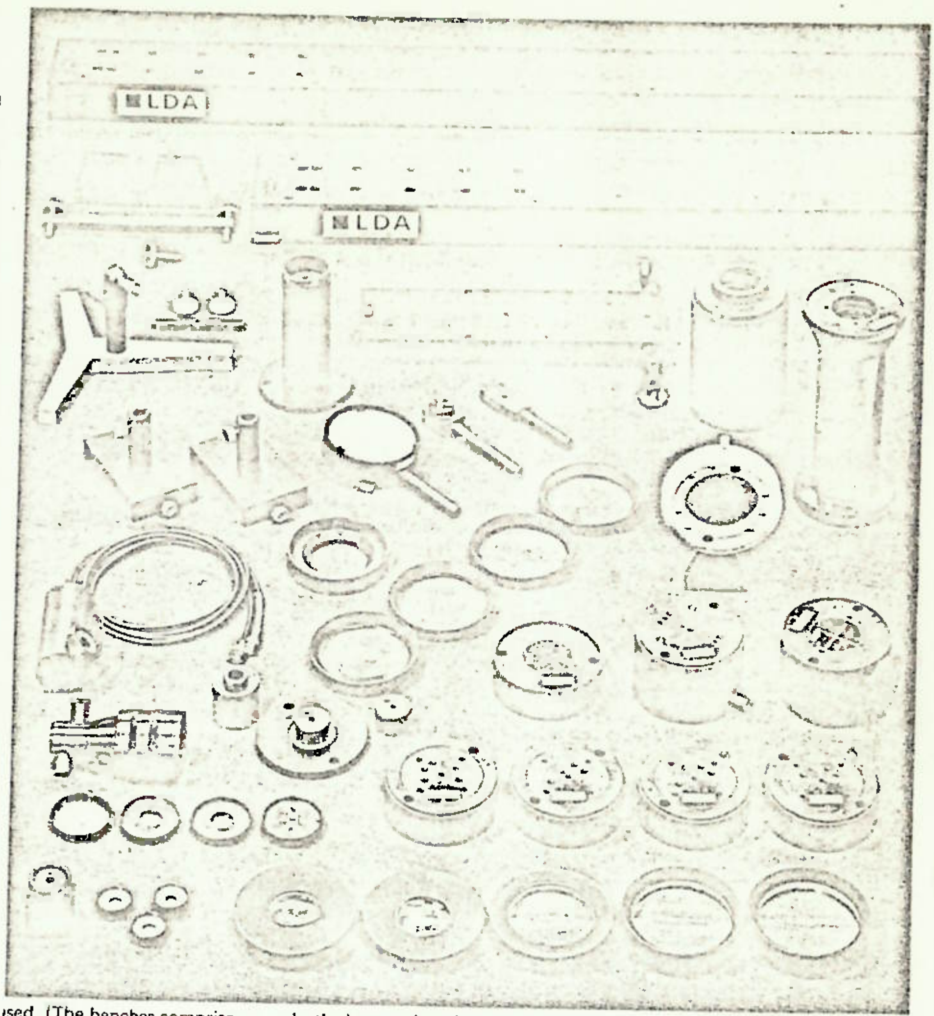
Features:

* Fully modular optical system
* Coaxial design
* Measured velocity vector plane can be rotated through 360°
* Hard anti-reflex coating on all optical surfaces
* Optical filters and coating rated for high power laser
* Optics corrected for spherical and chromatic aberrations
* Ball-bearing supports featuring graticules
* Beam expansion and full-aperture receiving optics for higher signal-to-noise ratio
* Adjustable receiving optics for precise focusing
* Only one frequency shift module and one backscatter module for one- and two-dimensional systems
* Mounting facilities for both HeNe-lasers and Argon-Ion lasers

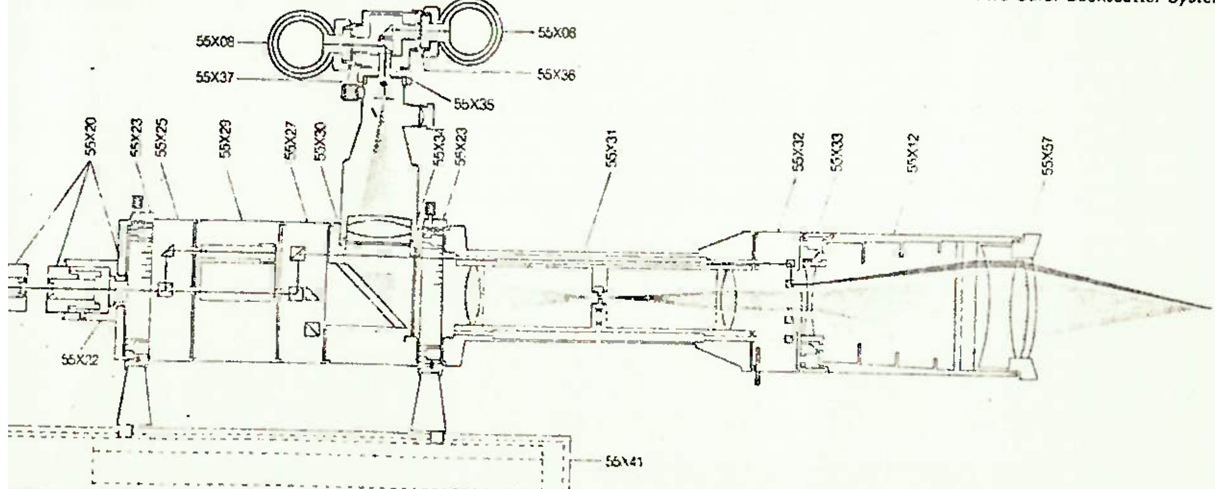
Introduction

The DISA 55X Modular LDA Optics constitutes a third generation in the development and design of laser Doppler optics. The overall optical layout is optimized for the utmost performance based on intensive research and developing experience from all types of LDA applications. Great care has been taken to develop the individual optical components (beam splitters, color separators, filters, etc.) utilizing advanced multilayer technique.

The typical LDA Systems for building up the 55X Optics for your application are shown on pages 14 and 15, with information on mode of operation. To start it, select the optical bench 55X19, 55X41 or 55X42) matching the laser head to be used. (The benches comprise mounting parts). Select one or two supports (55X23) for mounting the various modules, such as beam splitter, Bragg Cell, or beam translator. The modules feature standard lengths, inside screws, and guide pins for perfect mounting. Complete your LDA optics with a cover at the laser end, and a mounting ring with the actual front lens facing your investigation setup. In forward scatter modes the photomultiplier can be placed on the tripod (or clamped to your investigation setup), and in the backscatter mode be mounted together with the backscatter module.



The 55X Modular LDA Optics comprises a complete line of optical components for all modes of operation occuring in practice.



Two-Color Backscatter System

X Modular LDA Optics

(08 PM Section
s photomultiplier section
ises the PM tube and has a
eaded mounting ring for the
(36/37/38 Interference
ters. In a two-color setup two
Sections with Interference
ters are mounted to the 55X35
or Separator, which in turn
ounts to the 55X34 PM Optics.
otomultiplier Tube
RCA 4526
x. Cathode Voltage
2000 V, negative polarity
x. Anode Current
0.1 mA
ectrum Response
Ext. S20, quantum efficiency
14% (red) 20% (green/blue)
nsitivity
4400 A/W at 550 nm
ndwidth 0 to 120 MHz, 50 Ω
mensions
120 mm length, 52 mm dia
ight 0.5 kg

5X12 Beam Expander
he Beam Expander can be used
all 55X systems with variable
eam separation (55X32 Beam
ranslator). The Beam Expander
essential for applications in
hich the size of the measuring
olume is critical. By expanding
e laser beam the diameter the
easuring volume can be halved,
esulting in quadrupling of the
ght intensity.

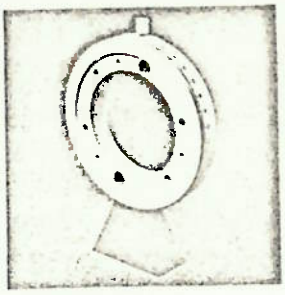
eam Expander Ratio
95 50
eam Expander Optics
Achromatic with hard AR-
coating. R<0 3% per surface
Dimensions
170 mm length, 112 mm dia-
meter
Weight 1.0 kg

55X19 Laser Adapter
The Laser Adapter comprises a holder for a coaxial laser head and a mounting bench with adjustable feet for the complete LDA Optics.

Coaxial Laser Diameters
50 mm or 44.5 mm
Dimensions
Adaptor tube: 165 mm length, 112/60 mm dia
Mounting Bench: 360 mm length, 108 mm width
Weigth
Adaptor tube: 0.5 kg
Mounting bench: 1.8 kg

55X20/21 Cover and Retarder
This set of Cover and Retarder is available for Argon-Ion laser 55X20 and for HeNe-laser 55X21. The λ/4 retarder is mounted on the laser head, and the cover with the retarder polarized laser beam will after passing these components have its polarization plane following the 55X Optics when this is rotated.
55X20 Cover and Retarder
Wavelength of light: 488 to 515 nm
55X21 Cover and Retarder
Polarization can be rotated relative to optics
Wavelength of light: 633 nm
Thread of Retarder λ/4 type
UNF 1" x 32 (laser head standard)
Dimensions
Cover: 112 mm dia
Retarder: 37 mm dia
Weight 0.3 kg

55X22 Beam Waist Adjuster
The Beam Waist Adjuster is used to optimize the fringe pattern quality in the measuring volume. It is important to adjust the laser beam divergence in a system having a front lens with long focal length. The 55X22 Adjuster mounts in the 55X20/21 Cover.
Adjustable Focal Length
-0 8 m to +0.5 m, beam expansion x 1.1
Dimensions
50 mm length, 43 mm dia



55X23 Support
One Support is used for mounting small 55X systems and two supports secures perfect stability of large optical systems. The optical benches have mounting holes for the supports.
Rotatability
360°, graticule ± 90°, ball bearing
Optical Axis
110 mm over bench
Dimensions
170 mm height, 126 mm, 17.5 mm thick
Weight
1.1 kg

55X24 Beam Splitter
This beam splitter module has a polarizing beam splitter prism, a polarisator rotator and a prism. The module has variable beam splitter ratio and is used in reference beam mode as well as in differential Doppler mode with photomultiplier. When operating in reference beam mode together with the 55L11 Diode Detector the polarisator rotator should be out of function (pull the small rod.)
Beam Splitter
polarization prism
633 nm
Polarization Rotator
90°, 633 nm
Beam Separation
One beam coaxial, one displaced 30 mm
Dimensions
35 mm width, 112 mm dia
Weight 0.7 kg

55X25 Beam Splitter
The 55X25 Beam Splitter has a neutral beam splitter and a prism, and is mainly used in two color setups.
Beam Splitter
Reflecting prism type
Beam separation
One coaxial beam, one beam separated 30 mm
Dimensions
35 mm width, 112 mm dia
Weight
0.7 kg

55X26 Beam Splitter

The 55X26 Beam Splitter is of a neutral type and splits an incoming coaxial beam into two beams parallel to the axis. This module is mainly used in 2-channel reference beam mode, and for one component measurement without frequency shift.

Beam Splitter
  Neutral prism type
Beam Separation
  Each beam separated 30 mm from optical axis, in the same plane
Dimensions
  35 mm width, 112 mm dia
Weight
  0.7 kg

55X28 Beam Displacer

The 55X28 Beam Displacer is used together with the 55X24 Beam Splitter in one-component setups (also with frequency shift)

Beam Displacement
  Incoming coaxial beam is displaced 30 mm by prisms
Dimensions
  35 mm thick, 112 mm dia
Weight
  0.7 kg

55X30 Backscatter Section

The Backscatter Section is used both in one-component differential mode and in two-component two-color mode. On the side of the section mounts the 55X34 PM Optics with one or two PM Sections.

Backscatter Mirror
  First surface type, coated
Backscatter Aperture
  50 mm
Dimensions
  70 mm width, 112 mm dia
Weight
  1 kg

55X32 Beam Translator

The Translator provides continuous variation of beam separation with stops at 13 mm 26-mm and 39-mm separation for one-channel operation. The same section is used in two channel systems.

Beam Translator, Internal Separations
  One channel: 13, 26, 39 mm
  Two channels: 9.2, 18.4, 27.6 mm
Prisms
  Reflection prisms
Dimensions
  35 mm width, 112 mm dia
Weight
  0.8 kg

55X27 Beam Splitter

The 55X27 Beam Splitter is of a color separating type and splits the incoming two-color beam into a green and a blue parallel to the axis. This module is used in two-color setups.

Beam Splitter
  Color sensitive prism type, 488/515 nm
Beam Separation
  Green and blue beams separated 30 mm from optical axis in the same plane
Dimensions
  35 mm width, 112 mm dia
Weight
  0.7 kg

55X29 Bragg Cell Section

This section will optically shift the incoming coaxial beam 40 MHz relative to the other. Both in case of one-channel and two-channel measurements, frequency shift can be added to the system by installing one 55X29 Bragg Cell Section. The section has been designed so that the optical path lengths of the two beams are equal.

Bragg Cell Frequency
  40 MHz
Signals for Bragg Cell Driver
  40 MHz, 1 Vrms at 50 Ω
  DC-voltage, 12 V, 300 mA at one BNC input socket
Bragg Cell Efficiency
  Max. diffracted light 85%
Dimensions
  70 mm width, 112 mm dia
Weight
  1.3 kg

55X31 Pinhole Section

The Pinhole Section is used in backscatter measurements (one- or two-channel) and depicts the measuring volume on the pinhole, thereby constituting a very efficient spatial filter eliminating undesired reflections from your flow setup.

Optical System
  Two achromatic lenses, aperture 50 mm
Pinhole Diameter
  0.5 mm
Pinhole Adjustment Range
  ±2 mm
Dimensions
  245 length, 112 mm dia
Weight
  1.8 kg

55X33 Lens Mounting Ring

The ring is used for mounting one of the 55X51-59 Front Lenses. When incorporating the 55X12 Beam Expander in the system this is mounted between the 55X33 and the front lens.

Internal Thread
  M105x1
Dimensions
  20 mm thick, 112 mm dia
Weight
  0.2 kg

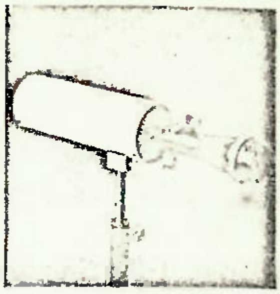
5X Modular LDA Optics

55X34 PM Optics
The photomultiplier optics is used both in forward scatter and backscatter modes. Its objective focusses on the measuring volume (with the aid of an eyepiece).
Objective
  Focal length: 150 mm, aperture 47 mm, achromatic
Variable Focus
  600 mm → ∞
Close-up Lenses
  Focal Lengths: 80, 150, 300 mm, Reference Beam Adapter
Pinhole Diameter
  0.1 mm
Pinhole Adjustment
  ±2 mm
Dimensions
  122 mm length, 60 mm dia
Weight
  0.5 kg

55X36/37/38 Interference Filter
These blue, green, and red narrow band filters are used for increasing the signal-to-noise ratio of the Doppler signals by filtering away unwanted light.
Wavelengths
  55X36: 488 nm
  55X37: 514.5 nm
  55X38: 633 nm
Transmission
  >75%
Bandwidth
  10 nm
Effective Filter Diameter
  12 mm
Dimensions
  33 mm dia, thread M30x1

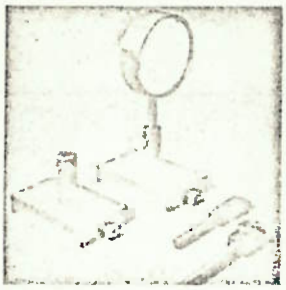
55X41/42 Mounting Bench
The bench mounts the laser head and the 55X Optics to a rigid system. The bench features fine adjustment facilities for the optical axis and has three adjustable feet. It includes mounting parts for the laser in question.
Dimension (HWL)
  55X41: 60x120x1750 mm (for Argon-Ion laser)
  55X42: 60x120x1400 mm (for HeNe laser)
Weight
  55X41: 9.0 kg
  55X42: 7.5 kg

55X43 Tripod
The tripod is useful for mounting the photomultiplier in forward scatter mode. The tripod comprises a spherical joint and holder for two PM Optics to be used in two component reference beam mode.



55L10 Photomultiplier
This photomultiplier with extra ordinary sensitivity covers applications with low and medium velocity. It is equipped with an eyepiece and an adjustable pinhole.
Type of PM Tube
  EMI 9658B
Voltage Range
  500 - 1400 V, negative
Overall Sensitivity
  Typical 1450 A/1m
Upper Frequency
  17 MHz at 1400 V
Objective
  Focal length 105 mm, 1:4
Close-up lenses Focal Lengths
  200 mm, 333 mm, 600 mm
Dimensions
  400 mm length, 75 mm dia
Weight
  2 kg

55X35 Color Separator
The separator is used in two-color systems and mounts two 55X08 PM Optics.
Color Separator
  Color separating beamsplitter prism
Separating Wavelengths
  488 or 515 nm, efficiency >98%
Dimensions (HWD)
  37x47x57 mm
Weight
  0.2 kg



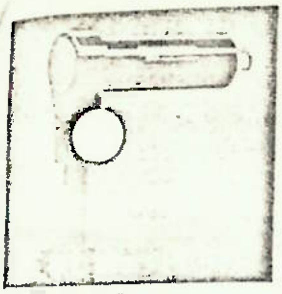
55X40 Accessories
This set of accessories comprises two supports, a surface mirror, a neutral density filter, and a test objective. The mirror is valuable when checking the optical alignment of the system, and the test objective is used for checking the beam intersection in measuring volume.
First Surface Mirror
  Diameter 100 mm, adjustable optical axis ca ±10 mrad 2 axes
Neutral Density Filter
  Attenuation: x 100 (488 to 514.5 nm)
Test Objective
  Focal length 4 mm
Weight
  Whole set 2.0 kg

55X44 Instrument Box
The instrument box has room for the various 55X modules and is of a flexible design.
Finish
  Mahogany
Dimensions (HWD)
  210x420x380 mm
Weight
  9 kg

55X51-59 Front Lens
A complete line of planoconvex and achromatic front lenses are available. The focal length corresponds to the distance to measuring volume (in air)
Coating
  Hard AR-coating, < 0.3% per surface
Diameter
  115 mm, thread M105x1

Type No.	Focal Length mm	Aperture mm	Weight kg
55X51, Planoconvex	300	94	0.2
55X52, Planoconvex	600	94	0.2
55X53, Planoconvex	1000	94	0.2
55X54, Planoconvex	1500	94	0.15
55X55, achrom.	80	48	0.6
55X56, achrom.	160	48	0.4
55X57, achrom.	310	80	0.5
55X58, achrom.	600	94	0.6
55X59, achrom.	1200	94	0.5

LDA Signal Processing



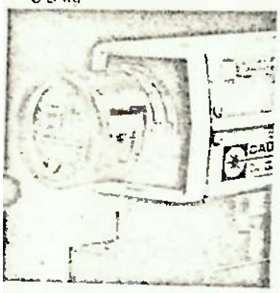
55L11 Diode Detector

The 55L11 Diode Detector comprises an aperture, a beam splitter, two photo diodes and a circuit board enclosed in a housing. The complete assembly is mounted in a support which allows one complete 360° rotation of the Diode Detector.

Sensitivity
  Typical 2V/mW at 200 kHz
Output
  max. 400 mVpp
Bandwidth
  2 kHz to 50 MHz (3 dB)
Beam Splitter
  Anti Reflex coated, polarized for 633 nm
Power Supply Voltage
  16 V DC, 40 mA
Output Impedance
  50 Ω

Length	Diameter
125 mm	31.5 mm

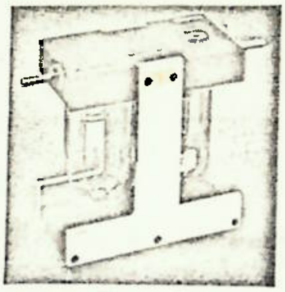
Weight
  0.3 kg



55L67 Optical Unit

The type 55L67 Optical Unit meets the need for a completely integrated optical unit that is easy to set up and requires no readjustment when beginning another measurement.

Beam Separation
  45 mm or 22.5 mm
Lens Focal Length
  120 mm and 300 mm
Optical Surfaces
  Hard coated anti-reflex front lens and beam splitter
  Quartz coated metal surface mirrors
Thread
  UNF 1" x 32 (laser head standard)
Dimensions
  60 mm dia. x 60 mm
Weight
  0.45 kg
Polarization Rotator
Code No. 9055C010



55L17 Seeding Generator

The operation of a laser Doppler Anemometer depends on the availability of particles to scatter incident light on to a photodetector. The particles must have a certain size to produce good Doppler signals and yet be small enough to follow the turbulence of the medium.

The DISA Type 55L17 Seeding Generator constitutes a valuable aid when performing LDA measurements in gaseous flows. The Seeding Generator comprises a carefully developed liquid atomizer and separator. The liquid to be atomized is poured into the Seeding Generator through a filler hole. Compressed air (gas) is fed through a reduction valve (not delivered by DISA) to the IN hose connector. A highly seeded gas flow for your investigation setup is available at the OUT hose connector.

Particle Density
  Approx. 5 x 10^5 particles/cm^3
Working Pressure (= differential Pressure between IN and OUT hose)
  0 to 150 kPascal (0 to 1.5 bars)
Maximum Supply Pressure
  600 kPascal (6 bars)
Testing Pressure
  1.5 MPascal (15 bars)
Nozzle and Separator Material
  Glass
Bowl Material
  Transparent polycarbonate plastic
Atomizing Liquid Volume
  Max. 110 cm^3
Hose Connectors
  8-mm dia.
Dimensions (HWD)
  170x160x90 mm
Weight
  1.7 kg

LDA Signal Processing

The instantaneous velocity V_x is represented by the Doppler heterodyning frequency f_D:

$$f_D = V_x \cdot \frac{\lambda_e}{2 \sin\theta/2}$$

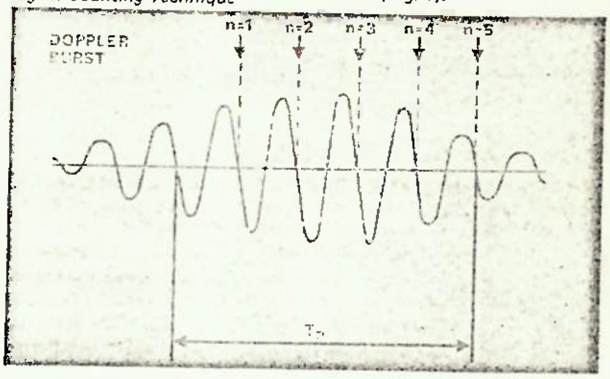
In all cases, however, demodulation and processing of the Doppler signal must be adapted to the type of flow under investigation. Flows having a low density of scattering particles will typically produce a signal consisting of short bursts with a good S/N ratio, separated by no-signal intervals. The LDA Counter Processor is ideal for processing this signal: It filters the photodetector signal to remove the DC component (DC pedestal) and the high-frequency noise, and thereafter uses the filtered Doppler bursts to gate a high-frequency clock during a known number of Doppler periods, n. After the gate has closed, the period time T_D of the Doppler signal can calculated by dividing the content of the clock register m_c by n. The Doppler frequency f_D can thus be found from

$$T_D = \frac{m_c \cdot T_c}{n} \Rightarrow$$

$$f_D = \frac{1}{T_D} = \frac{n}{m_c \cdot T_D},$$

T_c being the period time of the clock (Fig. 1).

Fig. 1. Counting Technique

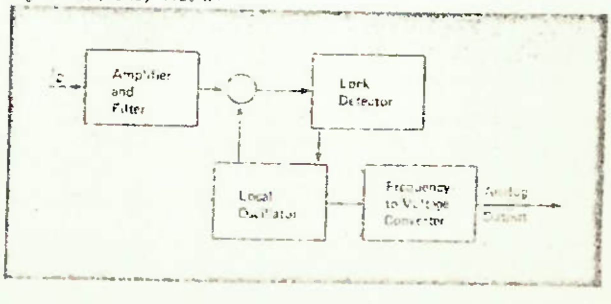


The use of high-speed logics and a high-frequency clock makes it possible to use LDA Counter Processor to measure flow velocities far into the supersonic range.

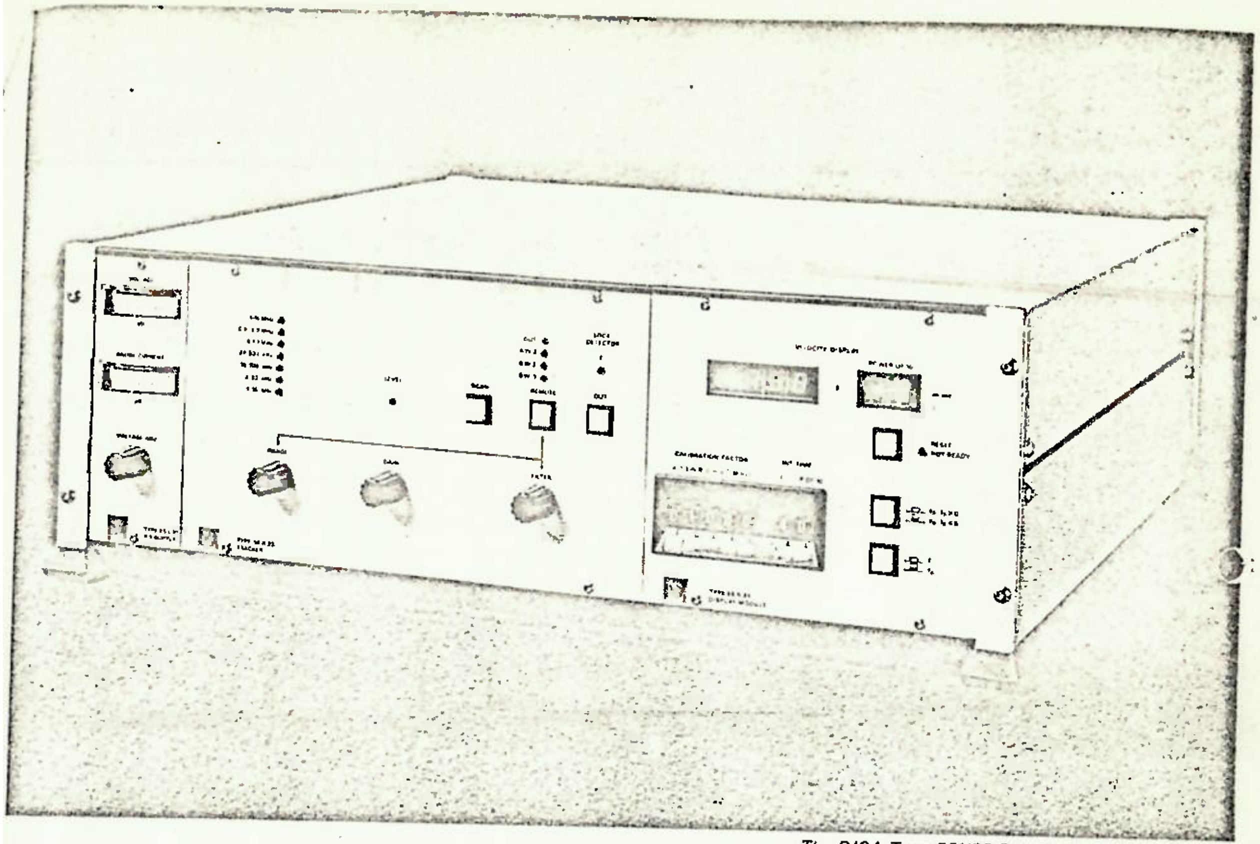
In flows having a high density of scattering particles it is possible to obtain Doppler signals in which coherent bursts are only separated by brief dropouts with random phase changes. The semi-continuous nature of the signal assures that no sudden changes in frequency will occur between consecutive bursts and allows the use of a tracking-type signal processor, the Doppler Frequency Tracker. The Doppler Frequency Tracker continuously compares the filtered Doppler signal with the output of a local oscillator, and any frequency difference between the two signals is used to lock the local oscillator to the Doppler frequency. Accordingly, by monitoring the continuous signal from the local oscillator it is possible to make real-time flow velocity measurements (Fig. 2).

Since the Doppler Frequency Tracker acts as a narrow-band tracking filter it is capable of processing even noisy photodetector signals that may occur under adverse measuring conditions.

Fig. 2 Frequency Tracker



55N20 Doppler Frequency Tracker



The DISA Type 55N20 Doppler Frequency Tracker

Advantages

* Total tracking frequency from 1 kHz to 10 MHz
* Covered by a total of seven separate overlapping ranges
* Each range has a 1 to 10 frequency ratio
* LED indication of tracker range selected
* Phase-locked-loop controlled VCO
* VCO frequency equal to Doppler frequency
* Lock detector with automatic lock-in search
* Spectrum analyzer function for simplified Doppler frequency detection
* Computer operated remote tracking range and filter control
* Input selector for choice of photomultiplier or diode detector
* Digital output panel for buffer and computer-interface
* Analog output with selectable low-pass filters
* Features a microprocessor for mean velocity calculation
* Direct m/s velocity display
* Calibration factor selection capability
* Averaging time selection of mean velocity display.
* Frequency shift compensation facility

Introduction

The DISA Type 55N20 Frequency Tracker is a completely new design in laser Doppler anemometry (LDA) instruments. It measures the instantaneous fluid flow velocity and presents direct m/s display. An analog output voltage is available for signal processing and digital outputs are available for computer analysis, as well.

The 55N20 Frequency Tracker is extremely simple to operate and features a logical front-panel layout. The rear panel contains all connecting terminals to provide versatile operation of the 55N20 Tracker with other instruments such as a frequency shifter or a mini-computer.

Modular Design

The 55N20 Frequency Tracker is made up of the following modules:

55N21 Main Frame
55N22 Power Supply
55N23 Tracker
55N24 Display Module (optional)
55L97 High Voltage Supply (optional)

The 55N24 Display Module calculates the mean velocity while the 55L97 HV Supply provides voltage for photomultiplier operation.

Principle

The incoming Doppler signals are amplified and filtered. These signals, together with the VCO-out signal, are fed to a phase detector. The phase detector signal goes to the Loop Integrator which in turn controls the VCO. The Analog Output signal originates at the Frequency-to-Voltage Converter and passes through the Output Filter. The VCO-control signal is also present here. The VCO output to the Digital Out circuit is formed by the counting circuit which counts the VCO over one complete time-period (both, positive and negative level shifts of the VCO are counted).

In the display Module the VCO counts are converted to the Mean Velocity Out display, with Frequency Shift compensation.

The Lock Detection circuit detects whether the Phase Locked Loop is in or out of lock. If out of lock, the Search function will startup and search for lock-in, to begin with close to the frequency where the lock was missed, and then with increasing cycle amplitude to cover the entire tracking range. The Lock Detection is delayed 500 VCO signal periods before searching begins. When the search is concluded the phase locked loop goes directly into lock.

The 55N20 Tracker can function as a Spectrum Analyzer; i.e. in the SCAN mode the VCO is swept through the range and the Lock Detector circuit is connected to the Mean Square Calculation. When displayed on an oscilloscope the Spectrum Out signal will show the actual Doppler spectrum.

Technical Data

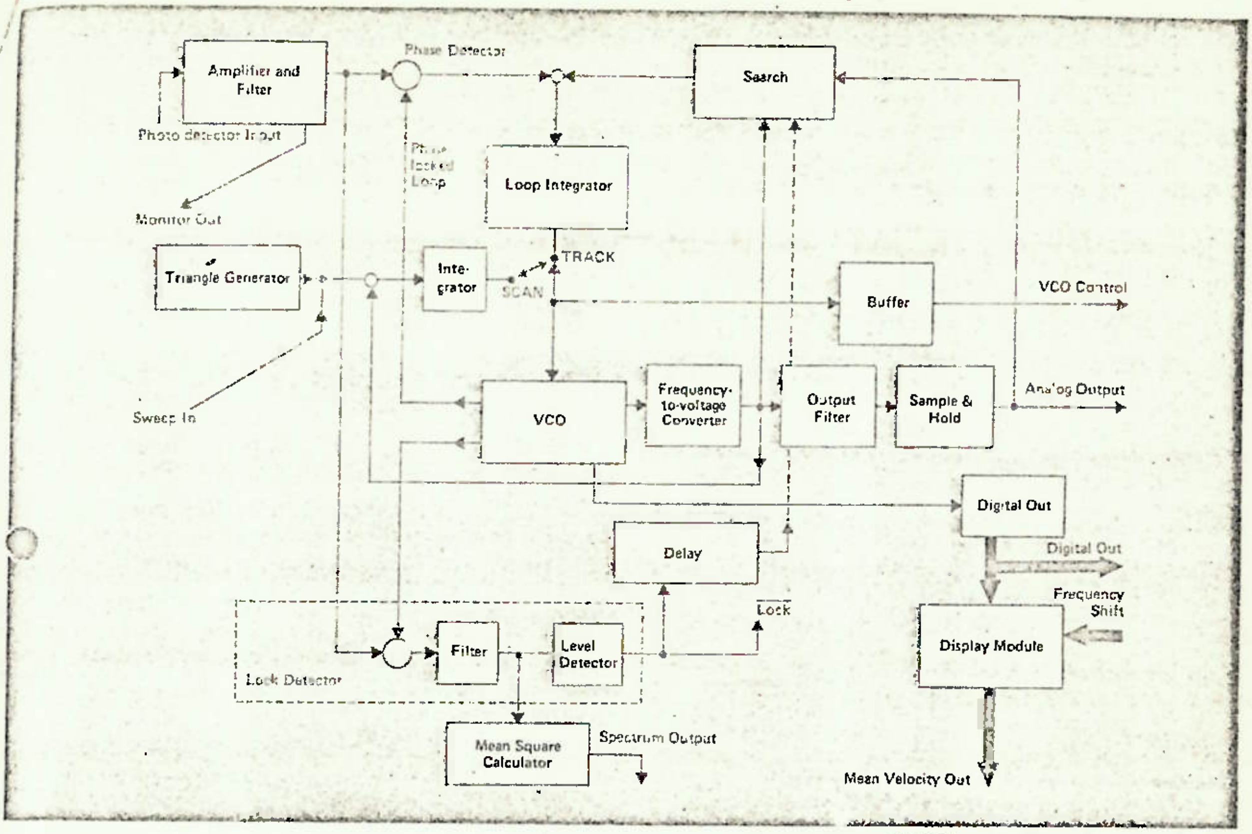
55L97 High Voltage Supply

Voltage Range
200 to 2000 V, negative polarity

Ripple
Max. 35 mVrms

Voltage Meter Range
0 to 2 kV

Anode Current Meter Range
0 to 100 μA



Simplified block diagram of the 55N20 Frequency Tracker

55N23 Tracker

Photodetector Input
Impedance: 50 Ω
Diode Detector: +18 V DC at 40 mA (R_i = 150 Ω)
Preamplifier Gain
40 to 90 dB
Equivalent Self-Noise
Typical 1.2 nV/$\sqrt{Hz}$, referred to input
Electronically Switched Filters
Controlled by RANGE selector
Monitor Out Terminal
50 Ω out
Use 50 Ω cable and high impedance load||max. 100 pF
Max. output level 400 mVpp
Type of Tracker Circuit
Phase-locked-loop
Lock Detection
Automatical search function
Frequency Tracking Ranges
1 to 10 kHz, 3 to 33 kHz, 10 to 100 kHz, 33 to 333 kHz, 0.1 to 1 MHz, 0.3 to 3.3 MHz, and 1 to 10 MHz
Upper Frequency for Flow Fluctuations
Maximum small signal tracking frequencies in resp. ranges:
0.74 kHz, 2.4 kHz, 7.4 kHz, 24 kHz, 74 kHz, 240 kHz, 0.74 MHz

Capture Range in resp. Freq. Ranges
±0.74 kHz, ±2.4 kHz, ±7.4 kHz, ±24 kHz, ±74 kHz, ±240 kHz, ±0.74 kHz
Maximum Slew-Rate in Resp. Ranges
210 kHz/sec, 630 kHz/sec, 6.3 kHz/msec, 63 kHz/msec, 630 kHz/msec, 6.3 MHz/msec, 63 MHz/msec
VCO Frequency Ranges
Equal to tracking ranges
Analog Output
Voltage range: 1 to 10 V for all seven ranges
Accuracy: 1% of full range
Impedance: 100 Ω
Output Filter
First order low-pass filter. Four settings in each tracking range. In 10 MHz range: 1.9 kHz, 5.9 kHz, 19.4 kHz and ∞
Spectrum Output
Voltage range: 0 to 10 V
Impedance: low
VCO Control Output
Voltage range: 1 to 10 V for all seven ranges
Accuracy: 4% of full range
Impedance: low
Sweep Input
Voltage range: 1 to 10 V
Impedance: high

Lock Detector signal
Open collector with 2 kΩ pull-up
Digital Input Terminal
Remote setting of range and output filter
Frequency shift information
Digital Output Terminal
Setting of range and output filter (values may be a result of local or remote settings)
Doppler frequency - 8 bits
Frequency shift information
Computer handshake signals

55N24 Display Module

Mean Velocity Display
3 digits with automatic selection of sign, decimal point after first digit
Power of 10 display: range from -9 to +9
Calibration Factor Range
10^{-3} to 10^{2} ms^{-1}/MHz
Integration Time Range
1 to 9X10^{3} sec
Range of Frequency Shift Input
0 to ± 9 MHz
Mean Velocity Output Terminal
Average Doppler frequency – 16 bits
Computer handshake signals

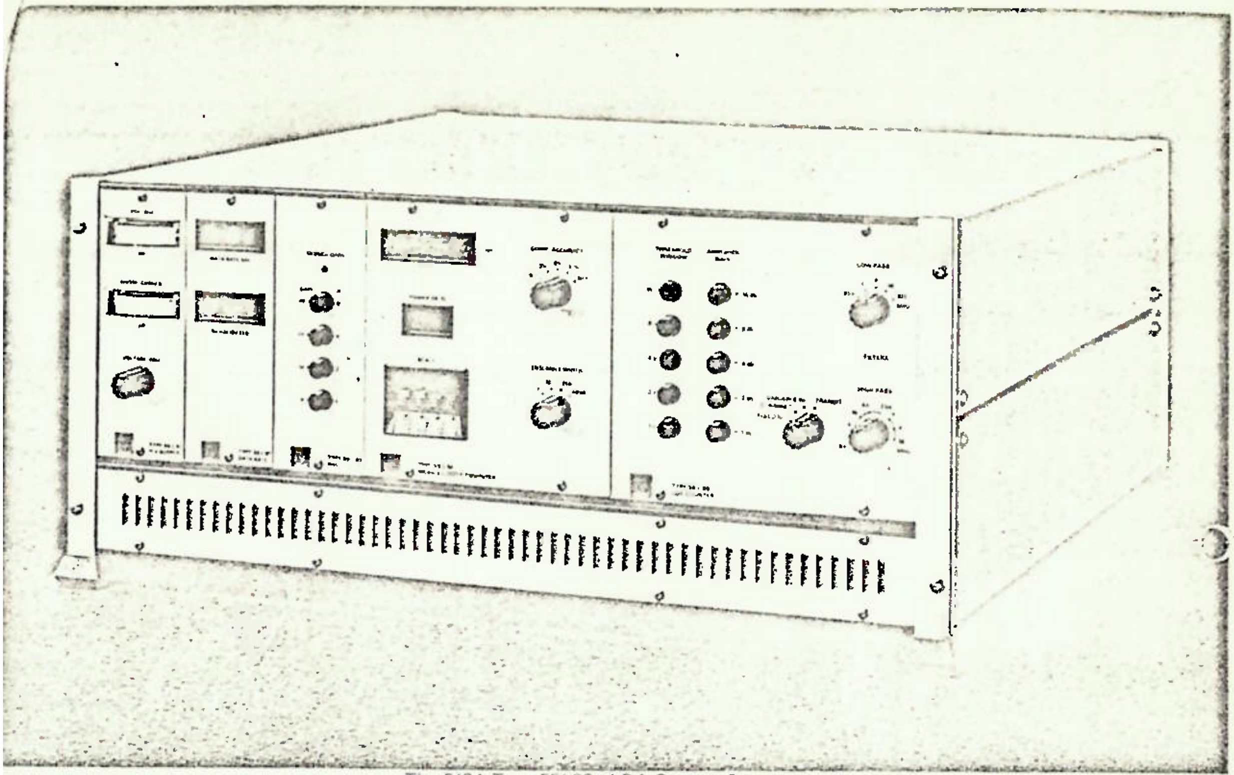
55N22 Power Supply

Line Voltage
For operation on any nominal line voltage from 100 to 129 and 200 to 259 V AC, 50 to 60 Hz.
Voltage selection by means of selector switch
Power Consumption
60 VA
Fuse
0.5/1.25 A at 220/110 V

Additional Data

Dimensions (HWD)
133 × 440 × 420 mm
Weight 11.6 kg

5L90a LDA Counter Processor



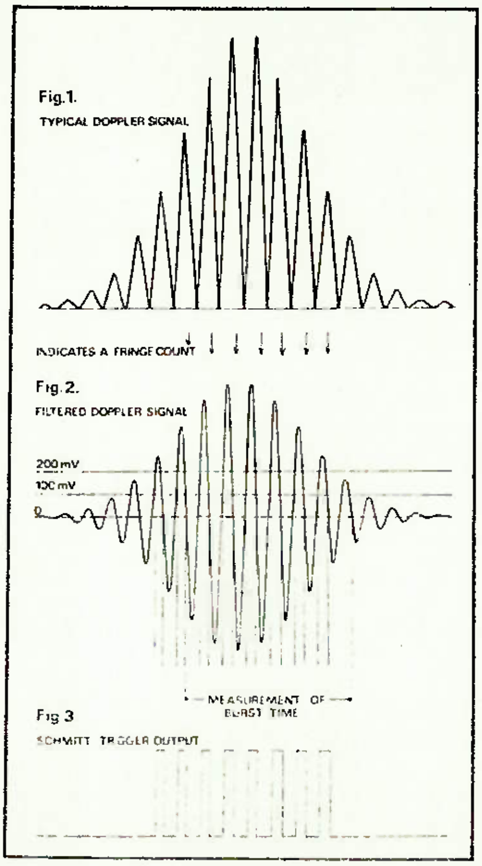
The DISA Type 55L90a LDA Counter Processor

'eatures

- Digital display of mean velocity in m/sec
- Auto ranging over full Doppler frequency from 2 kHz to 100 MHz
- Four modes of operation: Fixed, combined, variable and transit
- Advanced group of data validation circuits: amplitude domain validation with three Schmitt triggers
- Time domain validation by odd number (5/8) fringe count
- Automatic selection of number of fringes between 2 and 256
- True 500 MHz clock
- Total burst mode
- Digital display of data rate and percent validated data
- Large particle rejection circuit
- Data interface and buffer provided by 57G20 Buffer Interface
- High-pass and low-pass filters
- Digital and analog outputs

ıtroduction

leasuring the velocity of a fluid ow by means of a counting echnique is the latest developent in laser anemometry. Funamentally, the Counter times a attering particle over a known ımber of interference fringes ithin the measuring volume, ıus enabling evaluation of stantaneous velocity.



Doppler signal from a signal scattering particle and the output from the Schmitt triggers.

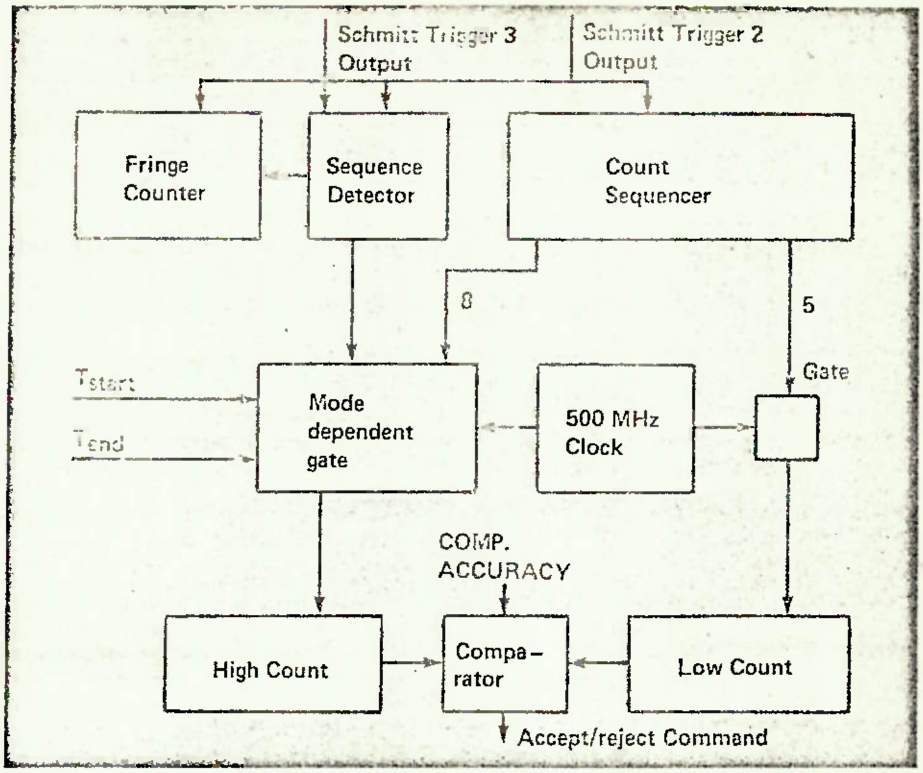
Principle

The separation between fringes is known from the geometry of the setup and wavelength of the laser light. A typical Doppler signal for a scattering particle crossing the center of the measuring volume is shown in Fig. 1. This signal is band-pass filtered to remove high-frequency and low-frequency noise, amplified and allowed to trigger a Schmitt trigger. Fig. 3 shows the resulting output from the Schmitt trigger. The period of this square wave is equal to the time it takes for a scattering particle to cross one fringe.

If the LDA Counter is operated in mode 1 (fixed N_f mode used mainly for almost continuous Doppler signals), operation is as follows: The Schmitt trigger output is fed to a control circuit which enables two high-speed counters (High Count and Low Count both counting a 500 MHz clock frequency) on the same zero crossing. After five fringe counts have been completed at the Fringe Counter input the Low Count is disabled. After eight fringe counts have occurred at the Fringe Counter input the High Count is disabled. A Comparator circuit then compares the Low Count with 5/8 High Count. An "accept" or "reject" command is released according to the desired accuracy (set by COMP. ACCURACY selector).

ın certain cases false data can pass through the Comparator. A Two Level Validation circuit comprising two Schmitt trigger levels and a Sequence Detector eliminates such false validation. If the comparison results in an "accept" command, the High Count, being directly proportional to the time it takes for the scattering particle to cross eight fringes, is inverted giving an output which is directly proportional to the instantaneous velocity. This result is passed to further processing circuits such as the 55L94 Mean Velocity Computer and 55L93 D/A Converter.

The LDA Counter is operated in mode 3 (variable N_f mode used mainly for "single burst" Doppler signals), operation is as follows:
The High Count register also in this mode is enabled on the zero crossing of the Schmitt trigger. It stays enabled as long as the Doppler signal is above a certain level. In this way the "burst time" is measured and at the same time the number of periods is counted by the Fringe Counter. These two data allow an interfaced computer to calculate the velocity and also to make very accurate corrections for bias.
The advantages of the two above-mentioned operating modes are combined in mode 2: Combined mode.
...tly it should be mentioned ... a mode of operation, the Transit mode (mode 4), is used for measuring the velocity of other particle transit phenomena. The time from one trigger event to the next (two channels) is measured and the inverted time is output.



Block diagram showing principle of operation.

Technical Data

The 55L90a LDA Counter Processor consists of the following modules which may be ordered separately, if desired:
55L96 Counter Module
55L97 High Voltage Supply Module
55L91 Data Rate Module
55L93 D/A Converter Module
55L94 Mean Velocity Computer Module
55L99 Power Supply

55L96 LDA Counter Module

Modes of operation
1. Fixed N_f mode
2. Combined mode
3. Variable N_f mode
4. Transit mode

Input Impedance
50 Ω
Input Frequency Range
2 kHz to 100 MHz
Calibration Factor Range
1.3 to 44 m/sec/MHz
(55X LDA Optics)
Velocity Range
3 mm/sec to 2000 m/sec
(approximate values for DISA LDA optics – dependent on geometry of setup)
Burst Time/Transit Time Range (mode 3, 4)
64 nsec to 4.2 msec
Number of Fringes
2 to 256
Low Pass Filter Settings
256 kHz
1, 4, 16, 100 MHz (3 dB)
Roll-off
60 dB/decade
High Pass Filter Settings
1, 4, 16, 64, 256 kHz
1, 4, 16 MHz (3 dB)
Roll-off
40 dB/decade
Threshold Window
20 dB in 1 dB steps
Instrument Limited Sample Rate
1.0 μsec + measuring time

Accuracy (∞SNR)(fixed N_f)
1 % at 40 MHz
2.5 % at 100 MHz
Digital High Pass Filter
Selects a minimum frequency or maximum measuring time

55L97 High Voltage Supply Module

Voltage Range
200 to 2000 V negative polarity
Ripple
Max. 35 mV rms
Voltage Meter Range
0 to 2 kV
Anode Current Meter Range
0 to 100 μA

55L94 Mean Velocity Computer Module

Digital Display
3 digits of velocity
1 digit of power of 10 with automatic selection of sign
Range of Scale Factor Setting
0 to 9999, Scale setting for velocity display in MHz: 0150

55L91 Data Rate Module

Data Rate Display
.000 to 999 kHz
‰ Validated Display
000 to 999 parts per thousand (based on last 1000 samples)

55L93 D/A Converter Module

Output Resolution
0.2 % of selected range
Output Impedance
600 Ω (DC)
Low Pass Filter
300 kHz (3 dB)
Roll-off
20 dB/decade
Output Range
0 to 1.25 V
Output Calibration Factor

$$f_D\,(MHz) = \frac{100}{2^A} \times V_{out}\,(V)$$

A = front panel gain setting

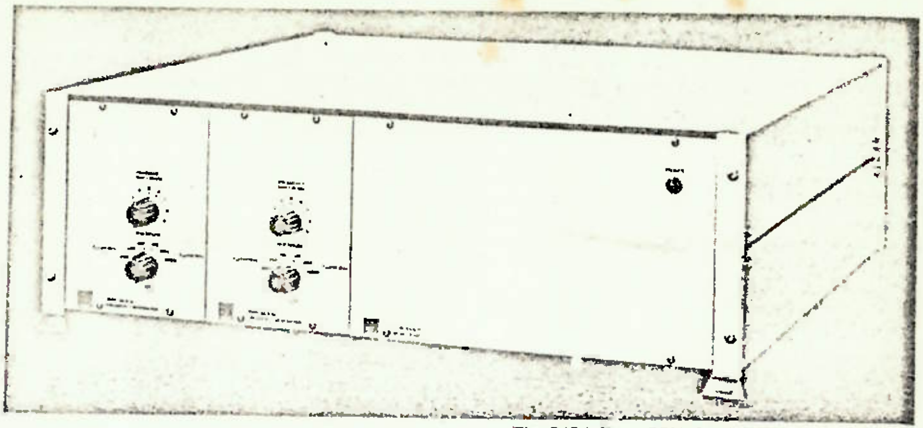
55L99 Power Supply

Line Voltage
For operation on any nominal line voltage from 100 to 129 V and 200 to 259 V AC, 50 to 60 Hz. Voltage selection by means of selector switch
Power Consumption
180 VA

Additional Data

Dimensions (HWD)
190 × 440 × 420 mm
Weight 16 kg

55N10 LDA Frequency Shifter


The DISA Type 55N10 LDA Frequency Shifter.

Features

- ★ Modular design – 1- or 2-channel version
- ★ Directly suitable for operation with DISA counters/trackers
- ★ Frequency shift range ±9 MHz
- ★ Provides 40-MHz signal for Bragg cell
- ★ Binary outputs facilitate computer interfacing

Applications

Optical and electronic frequency shifting allows measurements of highly turbulent and reversing flows such as:

- ★ Flow profiles with velocity reversals
- ★ Oscillatory flows of zero mean velocity
- ★ Vortex formation in wake flow
- ★ Natural convection flow
- ★ Unstable boundary layer flow

The DISA 55N10 LDA Frequency Shifter is operated in conjunction with LDA signal processors such as DISA counters/trackers. Because of its modular design both a 1-channel and a 2-channel version are available. Effective frequency shifts from 10 kHz to 9 MHz are provided on both channels, with individual frequency selectors.
The direction of the effective shift can be reversed relative to the sense of flow without re-adjustment or turning of the optics. A 40 MHz signal is provided for driving the Bragg cell for optical frequency shift. Terminals on the rear panel carry binary signals relating to the knob settings for the channels in question, for computer interfacing.

Technical Data

The 55N10 LDA Frequency Shifter comprises the following modules:

55N11 Frame with Mother Board
55N12 Mixer Unit
55N13 LM Exciter Unit
55N14 Frequency Shift Generator Unit
55N15 Fixed Divider Board
55N16 Power Supply

A one-channel setup comprises the following units: 55N11, 55N12, 55N13, 55N14, 55N15, 55N16. Expansion to a two-channel setup is effected by adding two extra sections: 55N12 and 55N14.

55N11 Frame with Mother Board

Consists of two D subminiature 9-spole female sockets with locking springs. The sockets are designated FREQUENCY SHIFT, DIGITAL OUT, CHANNEL 1 and CHANNEL 2.
The binary output of the DIGITAL OUT sockets indicates the setting of the FREQUENCY SHIFT GENERATOR UNIT. Output level is standard TTL with a fan-out of 4 per pin.

55N12 Mixer Unit

PM Input
Input impedance: 50 Ω
Input voltage range: 10 μ Vrms to 2.5 mVrms
Input frequency range: 10 MHz to 50 MHz
Equivalent input white noise spectrum: Typically 4 nV/$\sqrt{Hz}$

f_{LO} Input from 55N14
Input impedance: 500 Ω /560 pF
Input voltage range: 70 to 100 mVrms
Input frequency range: 30 MHz to 50 MHz

Mixer Out
Output impedance: 50 Ω
Conversion gain: Typically 15 dB
Output frequency range: 1 kHz to 20 MHz
Output voltage range: 56 μV to 14 mV
Anode current indication signal: Max. 200 μA.

55N13 LM Exciter Unit

General
Output frequency f_0 : 40 MHz ± 4 kHz
Frequency drift: 12.5 ppm
Frequency drift or frequency unstability is a term expressing the maximum change of frequency relative to 40 MHz taking place over a temperature range from 0° to 60°C.

40 MHz Output to Bragg Cell
Output voltage (adjustable): 0.1 Vrms to 1.7 Vrms into 50 Ω.
Output voltage, DC, unloaded: 15 VDC
Output voltage at max. 300 mA: 12 VDC
(load 50 Ω plus built-in 10 Ω limiting resistor)

40 MHz Output to 55N15 Fixed Divider Board:
Output Voltage: 40 mVrms into 50 Ω

55N14 Frequency Shift Generator

Output frequency: 40 MHz ± (1, 2, . . . , 9) x (10, 100, 1000) kHz.
Long term frequency drift: As for 55N13 (frequency locked)
Short-term frequency ripple (jitter): Typically ± 50 Hz.
Output voltage: 70 to 100 mVrms (unloaded)
Output impedance: 50 Ω
Spurious frequencies: Better than -30 dB relative to f_{LO}.
FREQUENCY IN KHz selector: 9 position switch selects factors between 1 and 9 kHz
MULTIPLIER selector: 6-position switch selects both frequency multiplication factor and sign of frequency shift (+ when f_{LO} > 40 MHz, - when f_{LO} < 40 MHz)

Input frequency: 2.5 kHz (40 MHz divided by 16000)
Input voltage: TTL level from 55N15

55N15 Fixed Divider Board

Input frequency: 40 MHz from 55N13
Input voltage: 40 Vrms
Input impedance: 50 Ω
Output voltage: TTL level to 55N14
Output frequency: 2.5 kHz (40 MHz divided by 16000)

55N16 Power Supply

Line voltage: 100, 120, 140, 200, 220, 240 VAC, 50/60 Hz. Stabilized against line voltage variations of ± 10%.
Power consumption: 40 VA
Output voltages: Stabilized +5 V and +15 V
Fuse: Slow-blow, 5 x 20 mm;
110 VAC: 0.63 A
220 VAC: 0.32 A

Additional Data

Ambient temperature range: +5° to +40°
Dimensions (HWD): 150 x 440 x 420 mm
Weight: 8.5 kg (2-channel version).

57G20 Buffer Interface

Features:
- ★ Provides communication between DISA Scientific Research Equipment and a PDP-11 Computer
- ★ Real-time data logging rate up to 1 MHz (10 MHz optional)
- ★ Simultaneous events logging in multichannel setup
- ★ Buffer of any length (expandable buffer)
- ★ Four double line input channels
- ★ Eight outputs for control of computer-operated auxiliary equipment
- ★ Ideal for operation with 55L90 Counter and 55N20 Tracker
- ★ Highly versatile

Introduction
The DISA 57G20 Buffer Interface system comprises a frame and a line of circuit boards for interface signal processing.

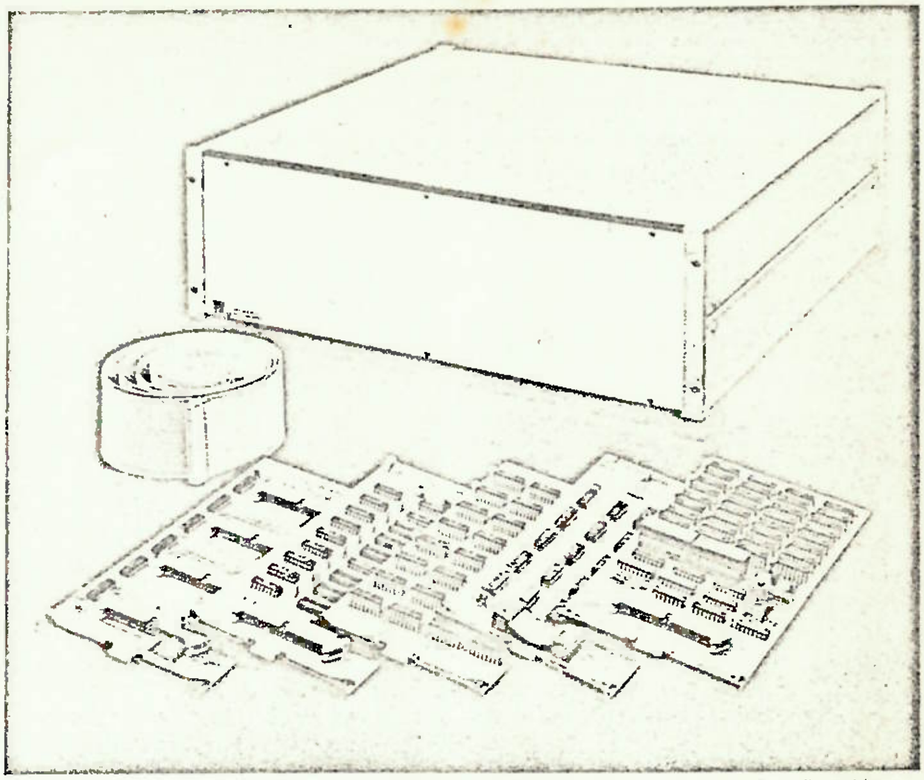
Units:

57B02	Main Frame
57G106	Control Logic
57G113	Output Demultiplexer
57G120	Input Multiplexer
57G127	Output Logic Buffer, ½k
57G134	Buffer Memory, ½k
—	+5V/- 12V DC-to-DC Converter
—	Coincidence Filter
—	Serial Transmission Line

The 57B02 Main Frame has a blank front panel and a rear panel carrying a power supply terminal. The Frame has a 40-channel series-operating backplane and will accommodate up to 10 circuit boards.

The 57G106 Control Logic circuit board controls data reading: It gives a priority order to the input channels in case of simultaneity, enables single or double input on the channels, matches input data to the buffer registers, and controls timing interaction and information in case of buffer overload. A socket for system self-testing is provided.

The 57G113 Output Demultiplexer is a self-contained communications circuit board. It demultiplexes output from the PDP-11 into eight channels, two of which are used to control functions (time base, ranges, etc.) of the DISA Counter/Tracker. The six are available for your computer controlled measuring setup, e.g. traversing.



The 57G20 Buffer Interface comprises a cabinet, flat cables, and circuit boards. Holders for rack mounting are also included.

The **57G120 Input Multiplexer** board has four double channels each of which connects through a 40-conductor flat cable to your DISA Counters/Trackers (ordering no.: 06A214 Flat Cable).

The **57G127 Output Logic Buffer** board comprises a variable length buffer register (maximum ½k 16-bit words), control logic for output data, and a +5V/ 12V DC-to-DC converter. This board buffers random asynchronous signals from your measuring setup into synchronous signals matching the Computer.

The **57G134 Buffer Memory** boards are used to expand your buffer capacity, each board by ½k.

The **+5V/- 12V DC-to-DC Converter** board powers the 57G134 Buffer Memories.

The **Coincidence Filter** board is intended mainly for two- or three dimensional velocity vector measurements. It blocks the Input Multiplexer except in case of data coincidence from the actual channels. This feature is of importance in cross-correlation computations. The coincidence time window is computer controlled.

The **Serial Transmission Line** (modem connection) board enables operation of your measuring setup in conjunction with a remote computer, e.g. a central computer.

Technical Data

57B02 Main Frame
Backplane
  2x41-pole board connectors
Number of Circuit Boards
  Max. 10
Power Supply
  +5V, max. 10A
  Rear panel socket: Fischer F-400A002+E
Dimensions (HWD) 133 x 440 x 420 mm
Weight 4 kg

57G106 Control Logic
Control Functions
  Computer handshake, priority order to input channels, single or double input to channels, adaptation of input data to buffer register, overflow indication of buffer, system self-testing.
Power Supply
  +5V, 250mA

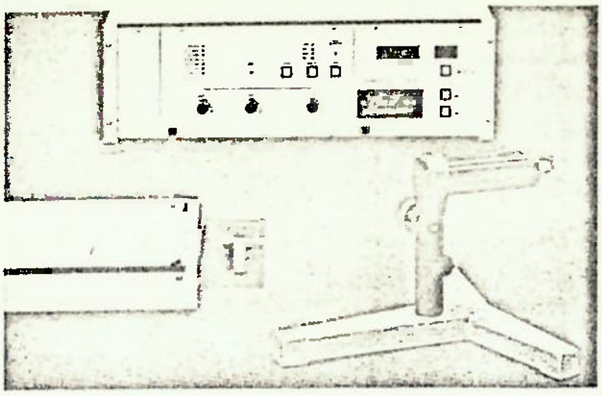
57G113 Output Demultiplexer
Input Terminal
  40-pole 3M 3432-1002 (mating plug type: 3417-3000 + 3490-5)
Demultiplexer Outputs
  6 TTL compatible external outputs (16 pin DIL sockets)
  2 outputs employed inside instrument
Output Signal
  12 bit word + reference ground and new data ready line
Power Supply
  +5V, 400mA

57G127 Output Logic Buffer
Buffer Register
  16-bit words, maximum length ½k
Input Rate
  Max. 1 MHz (10 MHz optional)
Control Logic
  Generates handshake to PDP-11
DC-to-DC Converter Output
  +5V to - 12V, 100mA (1 MHz version only)
Output Terminal
  40-pole 3M 3432-1002 (mating plug type: 3417-3000 + 3490-5)
Power Consumption
  +5V, 1.3 A

57G134 Buffer Memory
Buffer Register
  16-bit words, maximum depth ½k
Input Data Rate
  Max. 1 MHz (10 MHz optional)
Power Consumption
  +5V, 500 mA
  12V, 90mA (1 MHz version only)

DC-to-DC Converter
Power Supply
  +5V, depending on load (max. 3.5 A)
Output Voltage
  -12V, max. 1.2 A

Educational LDA System



Features

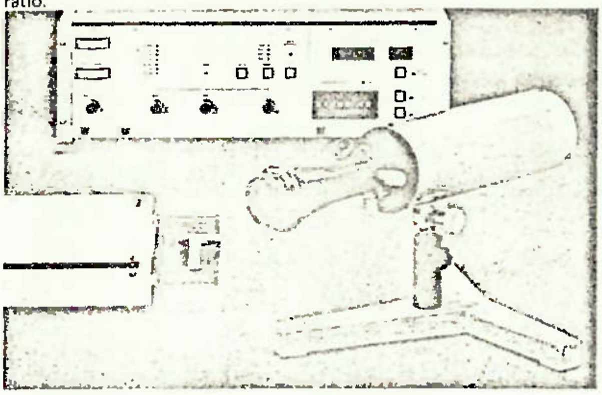
- Extremely easy to set up
- Very easy to operate
- Measured velocity vector rotatable through 90°

This tracker-based LDA System operates in the reference beam mode featuring extreme ease of optical alignment: Mount the 55L67 Optics on the laser head, select the proper front lens, and direct the 55L11 Diode Detector onto the measuring point with the reference beam impinging the Diode aperture. The system is well suited for water flow applications and the optical Doppler pedestal removal secures a very high S/N ratio.

System Data

Mode of Operation
Reference beam mode
Flow Medium
Water
Velocity Range
2 mm/s to approx. 50 m/s
Turbulence Intensity
Max. 30%
Distance to Point of Measurement
120 mm resp 300 mm

System Units
One 55N20 Doppler Frequency Tracker
One 55L67 Optical Unit
One Retarder Disc 9055C6101
One 55L11 Diode Detector



Low Velocity LDA System

Features

- Easy-to-operate system
- High sensitivity of photomultiplier
- Measured velocity vector rotatable through 90°

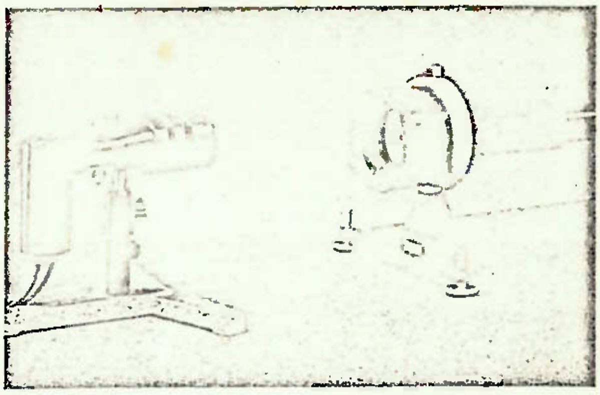
The low velocity tracker based system will operate in differential Doppler mode in water flows or moderately seeded air flows. Due to the extremely high sensitivity of the PM-tube this system is suited for flows with a particle concentration corresponding to only a single particle in the measuring volume at a time.

System Data

Modes of Operation
Differential Doppler mode
Flow Medium
Air (gas)
(Water)
Velocity Range
Approx. 2 mm/s to 50 m/s
Turbulence Intensity
Max. 30%
Distance to Point of Measurement
120 mm resp. 300 mm

System Units
One 55N20 Doppler Frequency Tracker, incl.
55L97 High Voltage Supply Unit
One 55L67 Optical Unit
One 55L10 Photomultiplier

Coaxial Laser System



Features

- Compact LDA optics
- Tracker-based or counter-based system
- Rotatable optics through 360°
- Wide range of front lenses

The coaxial laser system has adapters for mounting of most commercial laser heads. The LDA optics is light and compact, but the limited power of today's coaxial laser restricts the velocity range to low and medium. The flexibility of this system ensures measurements of one and two component forward scatter setups - three different beam separations - nine different front lenses are available.
You have a choice of selecting a tracker-based system which is well suited for liquid measurements or a counter-based system optimized for gas flows. In both cases operation of the systems is easy, featuring a mean velocity display direct in m/s.

55N20 Doppler Frequency Tracker

55L90a LDA Counter Processor

System Data

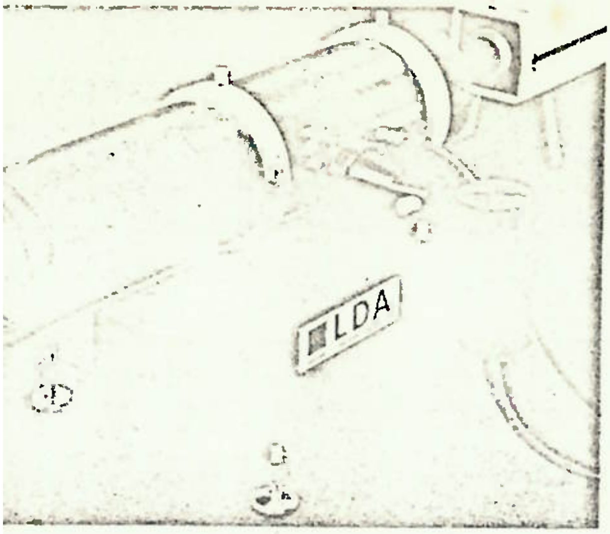
Modes of Operation
One component forward scatter in differential or reference beam mode
Two component forward scatter reference beam mode
Flow Medium
Tracker-based System: Liquid flow and highly seeded air flow
Counter-based System: Low seeded gas flow
Velocity Range (5 mW coaxial laser)
Tracker-based System:
Approx. 2 mm/s to 50 m/s
Counter-based System:
Approx. 2 mm/s to 100 m/s
Turbulence Intensity
Tracker-based System:
Max. 30%
Counter-based System:
Max. 50%
Distance to point of Measurements
80 mm to 1.5 m

System Units
One or two 55N20 Doppler Frequency Tracker, incl.
55L97 High Voltage Supply
or
One or two 55L90a LDA Counter Processor
One 55X51-59 Front Lens
One 55X23 Support
One 55X24 Beam Splitter
One 55X26 Beam Splitter
One 55X28 Beam Displacer

55X24 + 55X28 for single ch. diff./ref. mode
55X24 + 55X26 for two ch. ref. mode
55X26 for single ch. diff. mode

One 55X33 Lens Mounting Ring
One or two 55X08 PM Section
One or two 55X34 PM Optics
One or two 55X38 Interference filter (at high ambient light level)
One 55X19 Laser Adapter
One 55X43 Tripod

:kscatter LDA System



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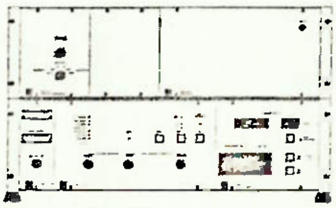
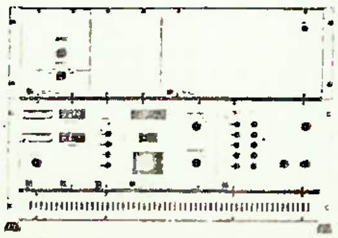
System Units
One 55L90a LDA Counter Processor
or
One 55N20 Doppler Frequency Tracker
One 55N10 Frequency Shifter (1-ch. version)
One 55X55-59 Achromatic Front Lens
One 55X08 PM Section
One 55X12 Beam Expander
One 55X21 Cover and Retarder
Two 55X23 Supports
One 55X24 Beam Splitter, pol. 633
One 55X28 Beam Displacer
One 55X29 Bragg Cell Section
One 55X30 Backscatter Section
One 55X32 Beam Translator
One 55X33 Lens Mounting Ring
One 55X34 PM Optics
One 55X38 Interference Filter
One 55X42 Mounting Bench (for 15 mW laser)
One 55X43 Tripod

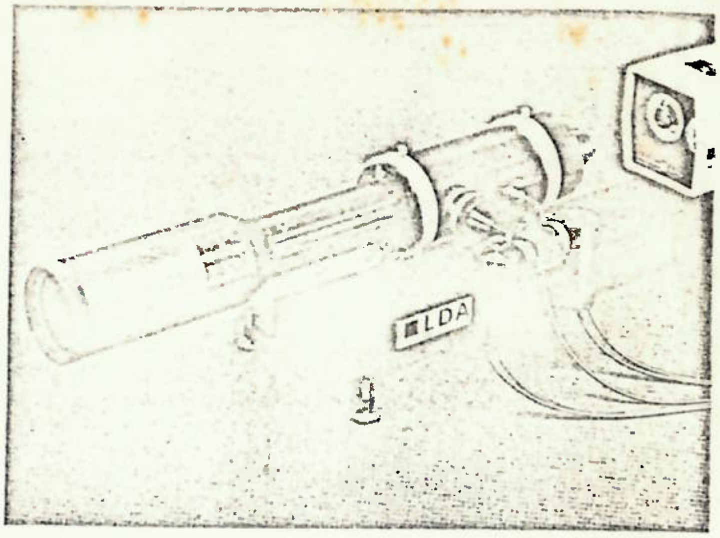


Tracker-based system with Frequency Shifter



Counter-based system with Frequency Shifter

Two-Color LDA System

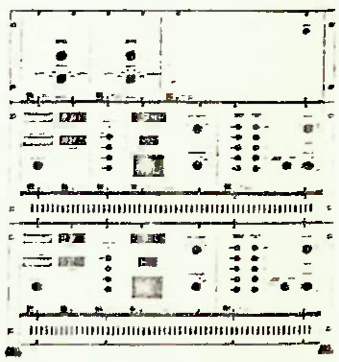


Features
* ★ Two-dimensional flow field investigations
* ★ Unseeded or sparsely seeded fluid flow measurements
* ★ Reynolds shear stress determination (correlation)
* ★ Supersonic flow measurements

Providing simultaneous measurements of two perpendicular velocity components, the Two-Color LDA System operates in differential Doppler backscatter mode. It utilizes the two strongest laser lines of an argon ion laser (green and blue lines) and the high output of the laser is of importance in supersonic measurements.
The electronics comprises two 55L90a Counters and a two-channel version of the 55N10 Frequency Shifter.

System Data
Modes of Operation
Two component two-color forward scatter and backscatter modes
Frequency Shift
Optical and Electronic
Flow Medium
Gases and liquids
Velocity Range
Approx. −300 to +1500 m/s (Mach 5)
Turbulence Intensity
Infinity
Distance to Point of Measurement
80 mm to 1.2 m

System Units
Two 55L90a LDA Counter Processors
One 55N10 Frequency Shifter (2-ch. version)
Two 55X08 PM Sections
One 55X12 Beam Expander
One 55X20 Cover and Retarder
One 55X22 Beam Waist Adjuster
Two 55X23 Supports
One 55X25 Beam Splitter
One 55X27 Beam Splitter
One 55X29 Bragg Cell Section
One 55X30 Backscatter Section
One 55X31 Pinhole Section
One 33X32 Beam Translator
One 55X33 Lens Mounting Ring
One 55X34 PM Optics
One 55X35 Color Separator
One 55X36 Interference Filter (blue)
One 55X37 Interference Filter (green)
One 55X41 Mounting Bench (For 5 W Argon Ion Laser)
One 55X40 Accessories
One 55X43 Tripod
Two 55X44 Instrument Boxes
One 55X55-59 Achromatic Front Lens



Two 55L90a LDA Counter Processors and a two-channel version of 55N10 Frequency Shifter

Computer System

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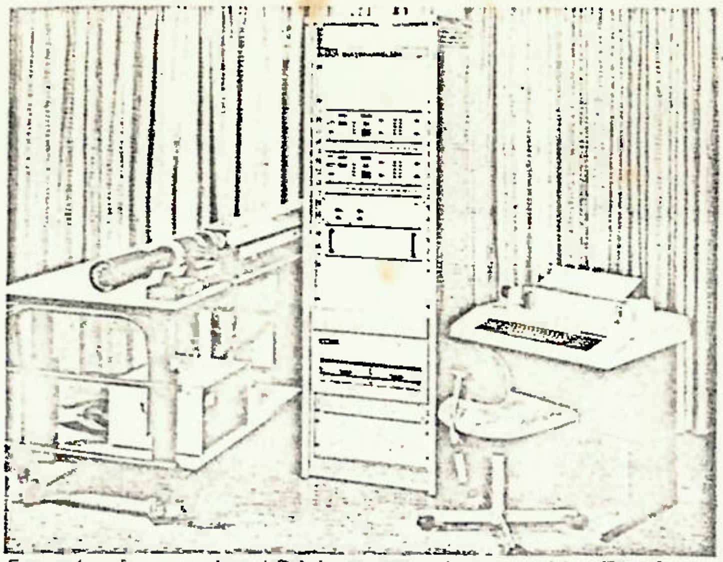


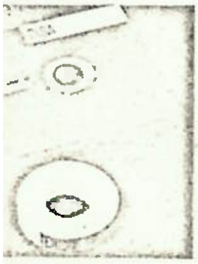
Example of a complete LDA instrumentation comprising Two-Color LDA Optics, two LDA Counter Processors, Frequency Shifter, Buffer Interface and Computer with keyboard terminal.

Software system
The DISA software system is designed as a number of libraries and as stand-alone programs. The distribution media are punched paper-tape and floppy disc. Having access to an operating system, the user can generate his own calculation programs and controlling facilities.
The following libraries are available:
Group 0:
This is a collection of test programs, which makes it possible to make hardware diagnostics in a very simple way. This library is always provided as a collection of stand-alone programs.
TEST: starts collection of data, and checks different facilities.
HELPME: is a separation test program. Using this program the hardware error area can be determined.
OUT: checks all optional outputs from the interface. Further there is a command system for manual testing.

Group I:
This is the data processing subroutine library. The primary design criterion has been data-collection speed. The second criterion is the best possible use of the memory area.
COLLEC: takes the arguments from the main section or any appropriate subroutine to set up the mode of operation, number of samples, and so on. In the standard version COLLEC supports 2 double channels.
COLLEC is device independent.
SORT: is an optional subroutine used to sort random data, if more than one channel is used. This procedure is time-consuming, and should be avoided in the case of non-random data.
TRANSF: is a level translating routine used to establish coincidence between the internal compressed format and the user format.
OUTP1: is a data transmission program used to organize the transmission of collected data to a storage device or a background computer.
SCAN: gives high-level control over optional outputs, traversing control, etc.

Group II:
This is a collection of calculation subroutines. They are all generated in FORTRAN, and they can be supplied as user written routines or changes. They are all called from a main section, and they must have access to group I or a similar library.
DATA: is the high level data transmission program. It calls TRANSF, and calculates data in user units.
DATAI: is the data-list program. It is used as a diagnostic program to check the setup.
MOMEN: calculates the moments of the distribution function.
HISTO: generates the histograms for all available channels.
CORR: calculates possible components of the correlation functions, both auto- and cross-correlations are available.
SPEC: calculates the spectra based on the correlation functions.

computer operated
ng systems



Print-out on monitor screen of the processing program

Data list showing velocity and time information

Histogram showing velocity distribution

ISA
DISA ELEKTRONIK A/S . DK-2740 SKOVLUNDE . DENMARK
Telephone: + 45 2 84 22 11 . Cables: DISAELEKTRONIK, Copenhagen . Telex: 35349 disae dk

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