اثر داپلر به تغییر بسامد امواج صدا و نور متناسب با سرعت منبع صدا یا نور

CHAPTER VI

DOPPLER LOG

GENERAL DESCRIPTION

تغییر بسامد صدا بخاطر آثر داپلر   مبنا

Doppler log is based on the principle of Doppler shift in frequency measurement i.e. apparent (ظاهری . قابل درک) change in frequency received when the distance between source and observer is changing due to the motion of either source or observer or both. In Doppler log an observer is moving with a source of sound towards a reflecting plane (سطح قابل بازتاب), then the received frequency

$$fr = ft \ (c + v) / (c - v)$$

where fr = received frequency

ft = transmitted frequency

c = velocity of sound in seawater and

v = velocity of the vessel

By measuring the received frequency (fr) & knowing the value of transmitted frequency (ft) and velocity of sound in seawater (c), the speed of the vessel v can be determined.

رساننده انرژی از یک دستگاه به دستگاه دیگری یا تغییر دهنده نوع انرژی مثلا تبدیل کننده انرژی برق به صدا در بلندگو

PRINCIPLE

A transducer is fitted on the ship's keel which transmits (انتقال) a beam (پرتو یا اشعه) of acoustic (صوتی) wave at an angle α usually 60° to the keel in the forward direction, this gives the component (جزء یا بخش) $v \cos \alpha$ of the ship's velocity towards the sea bed thus causing the Doppler shift and the received frequency

$$fr = ft \ (c + v \cos \alpha) / (c - v \cos \alpha) \quad \text{.............. (i)}$$

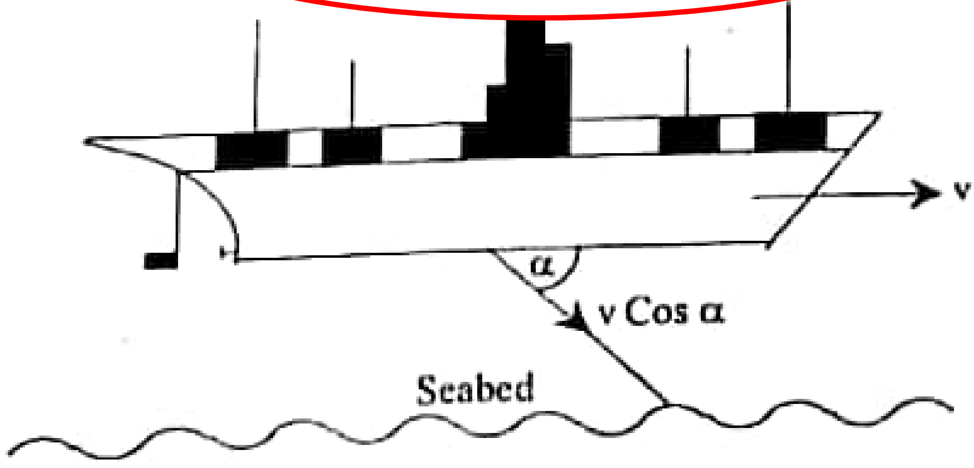


Figure 1
Acoustic beam transmitted at an angle α towards seabed

$$fr = ft\,(c + v\,\mathrm{Cos}\propto)\,/\,(c - v\,\mathrm{Cos}\propto) \quad \ldots\ldots\ldots\ldots \quad (i)$$

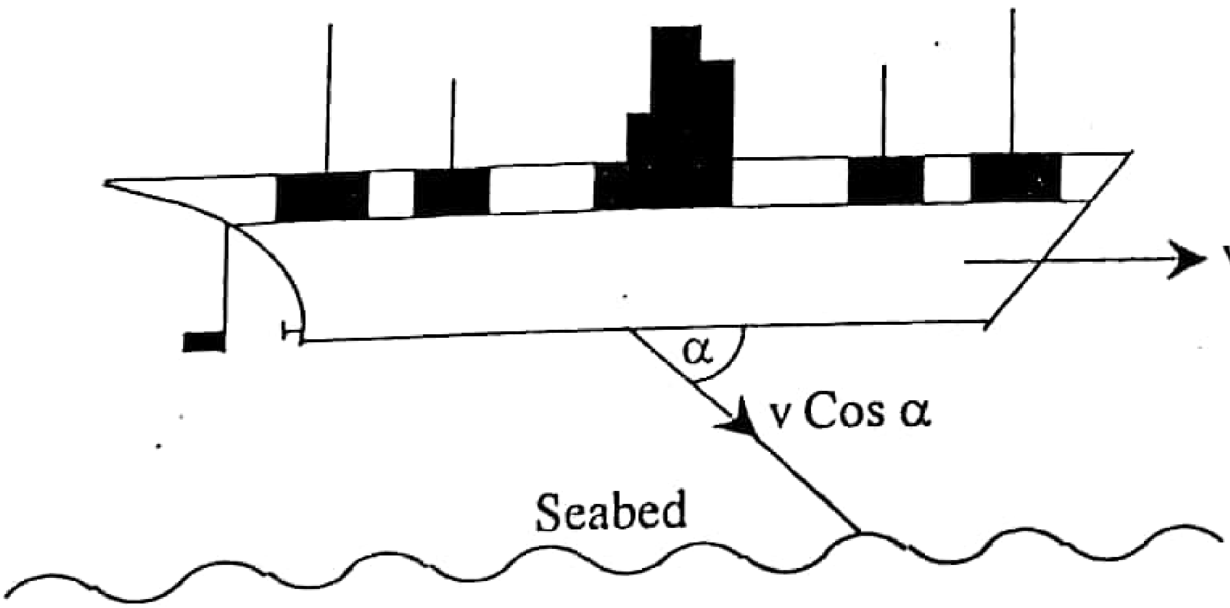


Figure 1

اثبات ها نیاز نیست فرمول اول مورد نیاز است

If the waves are transmitted directly towards the seabed perpendicular to the keel, there will be no Doppler shift and the transmitted and received frequency will be the same. This is because the component of ship's speed towards the seabed is zero (i.e. v Cos 90).

According to the Binomial expansion, we have

$$1/(1 - x) = 1 + x + x^2 + x^3 + \text{-------} \quad \text{(ii)}$$

Dividing numerator and denominator of equation (i) by c, we get

$$fr = ft\,(1 + v \cos \alpha / c) \times \frac{1}{(1 - v \cos \alpha / c)}$$

By using the formula (ii) in this equation and on simplification we get,

$$fr = ft\,(1 + 2 v \cos \alpha / c + 2 v^2 \cos^2 \alpha / c^2 + \ldots)$$

since $v \cos \alpha << c$, neglecting higher powers of $v \cos \alpha / c$ we get,

$$fr = ft + 2 v\, ft \cos \alpha / c$$

$$fr - ft = 2v\, ft \cos \alpha / c \quad \ldots\ldots\ldots\ldots\ldots\text{(iii)}$$

$$v = c\,(fr - ft) / 2\, ft \cos \alpha. \ \ldots\ldots \ \text{(iv)}$$

With the help of this formula we can calculate the speed of the ship, considering that there is no vertical motion.

In practice the ship has some vertical motion and the Doppler shift measurement will have a component of this vertical motion. In this case Doppler shift measurement will be

$$fr - ft = 2 v\, ft \cos \alpha / c + 2 V_v\, ft \sin \alpha / c$$

$$fr - ft = (2 v\, ft \cos \alpha + 2 V_v\, ft \sin \alpha) / c \quad \ldots\ldots\text{(v)}$$

where V_v represents the vertical motion of the ship.

This problem is overcome by installing two transducers, one transmitting in the forward direction and another in the aft direction at the same angle. This arrangement is known as Janus configuration as shown in figure 2. In this case the forward transducer will give Doppler shift

$$\text{i.e. } fr_f - ft = 2 v\, ft \cos \alpha / c + 2 V_v\, ft \sin \alpha / c$$

$$fr_f - ft = (2 v\, ft \cos \alpha + 2 V_v\, ft \sin \alpha) / c \quad \ldots\ldots\text{(vi)}$$

where fr_f is the frequency received by the forward transducer

while the aft transducer will have the component $v \cos \alpha$ with negative sign since the transducer is moving away from the reflecting surface i.e. the seabed and hence the Doppler shift measured will be

$$fr_a - ft = -2 v\, ft \cos \alpha / c + 2 V_v\, ft \sin \alpha / c$$

$$fr_a - ft = (-2 v ft \cos\alpha + 2 V_v ft \sin\alpha) / c \quad \text{.............. (vii)}$$

where fr_a represents frequency received by the aft transducer.

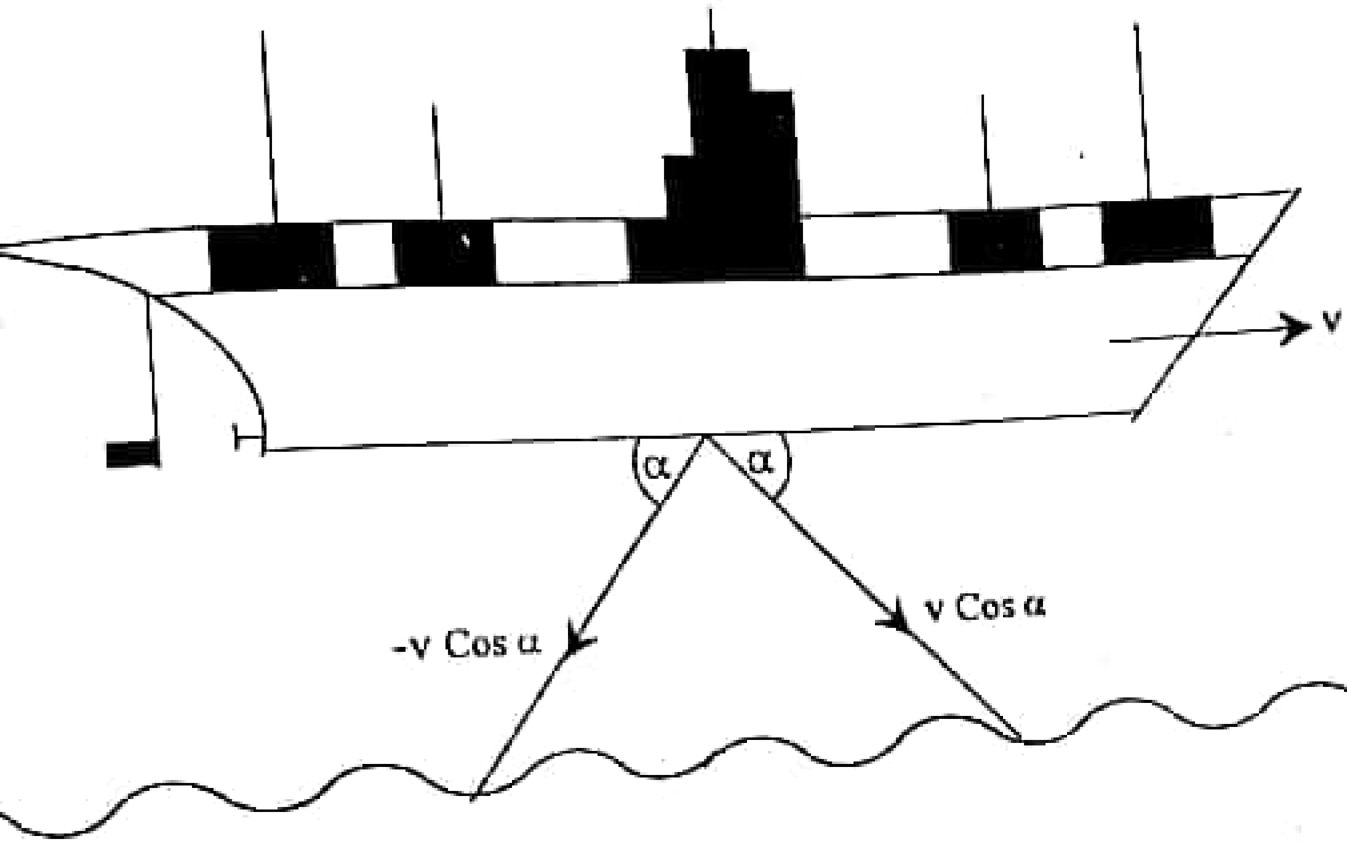


Figure 2
Janus configuration

In formula (vi) and (vii) Vv will have the same sign since both the forward and aft transducers will move upwards or downwards together.

By measuring the difference between the two Doppler shift frequencies, the vertical component will cancel out while the horizontal will add i.e.

$$(fr_f - ft) - (fr_a - ft) = (2 v ft \cos\alpha + 2 V_v ft \sin\alpha) / c$$
$$- (-2 v ft \cos\alpha + 2 V_v ft \sin\alpha) / c$$

$$fr_f - ft - fr_a + ft = 2 v ft \cos\alpha / c + 2 V_v ft \sin\alpha / c$$
$$+ 2 v ft \cos\alpha / c - 2 V_v ft \sin\alpha / c$$

$$fr_f - fr_a = 4 v ft \cos\alpha / c$$

$$\text{i.e. } v = c (fr_f - fr_a) / 4 ft \cos\alpha \quad \text{....(viii)}$$

Thus v i.e. speed of the ship can be calculated. The speed of the ship as determined by the above formula is the speed over ground, unaffected by set and drift since the echoes are coming from the seabed. This is also referred to as **bottom track or ground track.**

دستگاه میتواند سرعت کشتی را هم براساس گراند ترک و همچنین واتر ترک محاسبه کند زمانی که از واتر ترک استفاده میکند از لایه های 10 تا 30 متری زیر کشتی استفاده میکند اما زمانی که گراند ترک ارمحاسبه میکند از کف دریا استفاده میکند

فرق:در کالژن اویدنس از آواتر ترک استفاده میکنند زمانی که در بندر و برای ورود یا مانورمهمی که حرکت وضعیآن مهم است از گراند ترک استفاده میشود

The transmitted pulse has certain power and can go up to a limited depth usually 200 meters. Beyond this depth, the echoes from the seabed become very weak and the strength is not sufficient to calculate the Doppler shift.

In such a case echoes are also available from water layers between 10 and 30 meters below the keel and hence Doppler shift is possible, enabling measurement of speed. But this will give us speed over water. This is referred to as water track and does not allow for set and drift. The equipment automatically changes over to water track when the echoes from the seabed are not strong enough

When the ship moves at high seas at the usual sea speed it carries some mass of surrounding water with it and thereby providing a distinct layer of water between 10 and 30 meters below the keel and this depth depends on the draft and speed of vessel. Below this depth the water is still and hence there is a distinct separation between the two layers of water which provides the echoing surface of the acoustic waves. These echoes are of course weak since the echoing surface is actually liquid, but stronger than the echoes coming from the depths of over 200 meters. The speed worked out does not depend on the depth from which the echoes are received. The strength of the echoes indicates whether the ship is on bottom track or on water track.

ATHWARTSHIP'S SPEED

Doppler log on ground track mode can provide athwartship's speed as well and for this purpose a similar Janus configuration is used on the port and starboard sides. The athwartship speed is calculated in the similar manner as mentioned above.

EFFECT OF VARIOUS SHIP CONDITION AND SHIP MOTION

- **Heaving**

Any vertical movement Vv will have component Vv sin α in the direction of the acoustic wave, resulting in an error in Doppler shift

$$= 2\ Vv\ ft\ \text{Sin}\ \alpha / c.$$

Hence the Doppler shift measurement at forward transducer will be given by

$$fr_f - ft = 2\ v\ ft\ \text{Cos}\ \alpha / c + 2\ Vv\ ft\ \text{Sin}\ \alpha / c$$

and that at the aft transducer will be given by

$$fr_a - ft = -\ 2\ v\ ft\ \text{Cos}\ \alpha / c + 2\ Vv\ ft\ \text{Sin}\ \alpha / c$$

By measuring the difference between the two Doppler shift frequencies, the vertical component will cancel out while the horizontal will add i.e.

$$(fr_f - ft) - (fr_a - ft) = (2 v ft \cos\alpha + 2 V_v ft \sin\alpha)/c$$
$$- (-2 v ft \cos\alpha + 2 V_v ft \sin\alpha)/c$$

$$fr_f - ft - fr_a + ft = 2 v ft \cos\alpha / c + 2 V_v ft \sin\alpha / c$$
$$+ 2 v ft \cos\alpha / c - 2 V_v ft \sin\alpha / c$$

$$fr_f - fr_a = 4 v ft \cos\alpha / c$$

Therefore, $v = (fr_f - fr_a)\, c / 4 ft \cos\alpha$

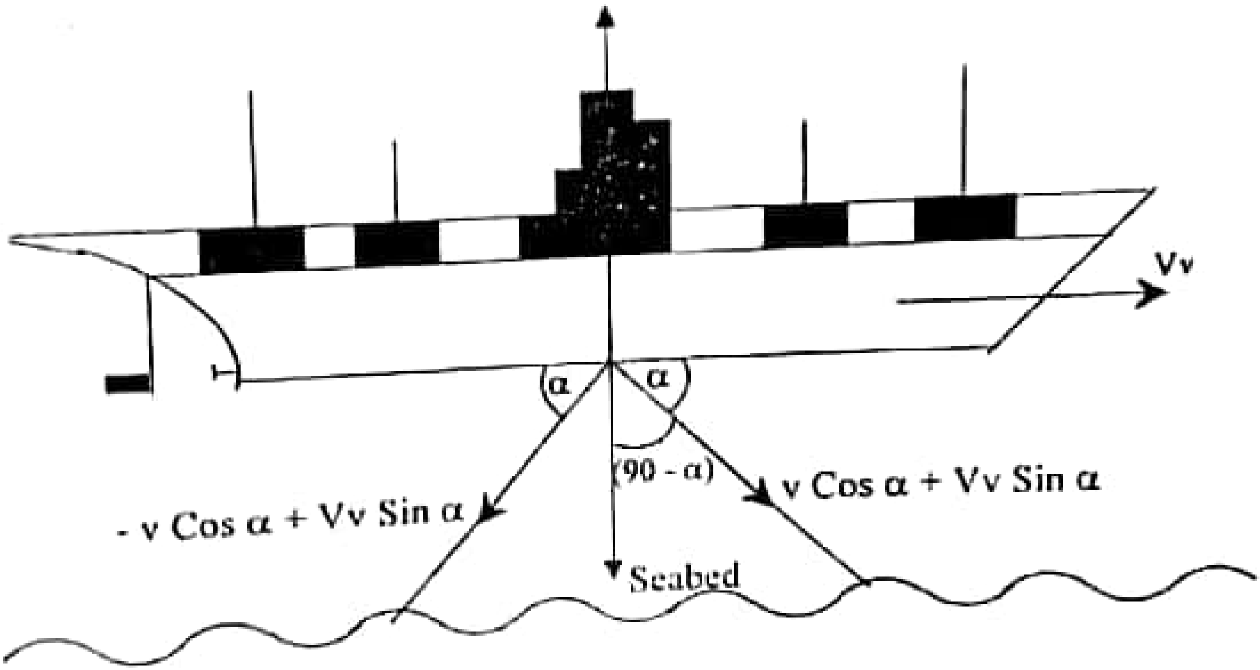


Figure 3
Effect of heaving

Thus any vertical movement has got no effect on the speed indicated.

➢ **Trim**

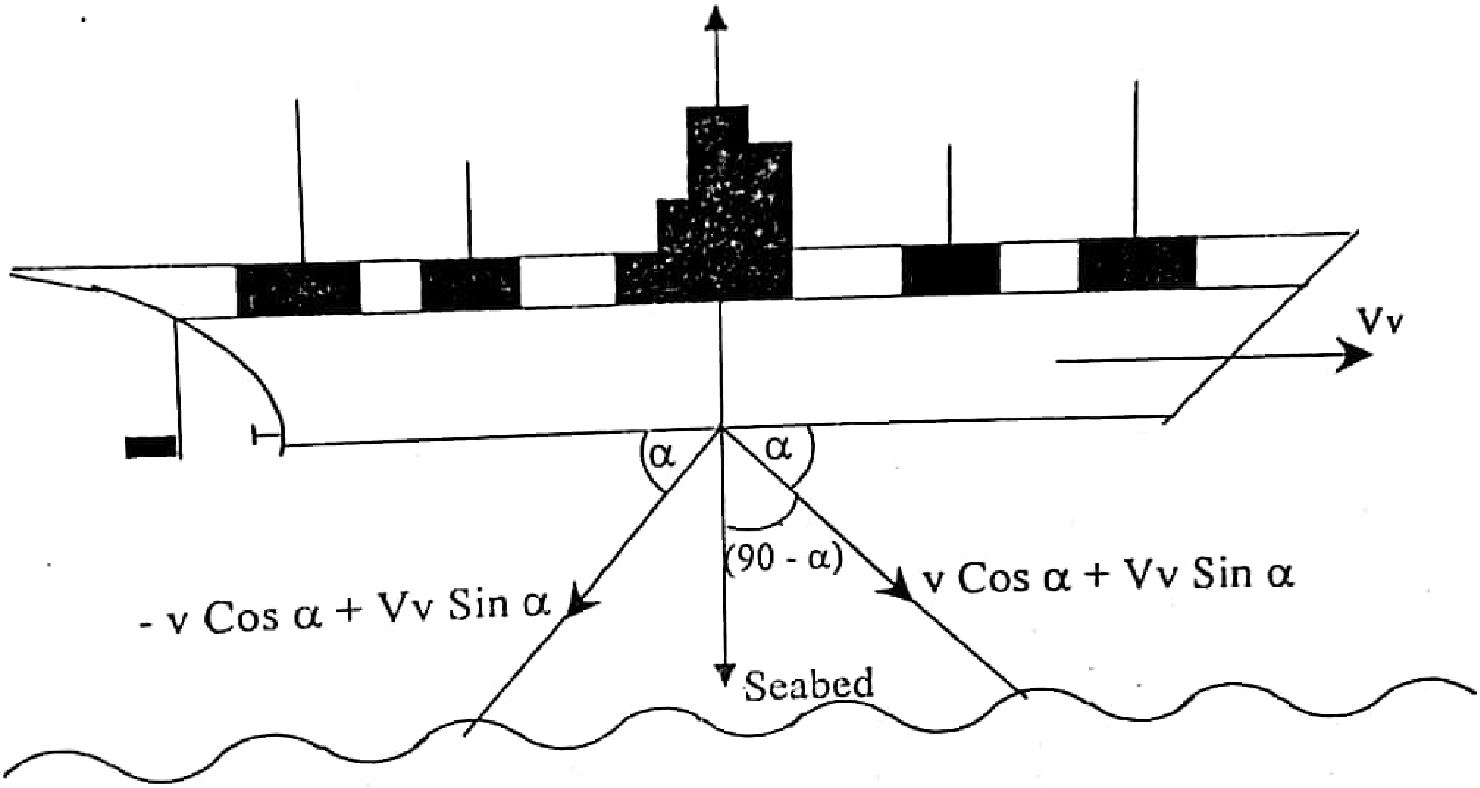
** The trim of the vessel has very less affect on fore and aft speed and no affect on athwartship speed.

- **When down by stern**

When trimmed by an angle β, the forward transducer will transmit at an angle (α - β) while the aft transducer will transmit at an angle (α + β) as shown in figure 4 and the Doppler shift frequency measurement by the forward transducer will be

$$fr_f - ft = 2 v ft \cos(\alpha - \beta)/c$$

while the Doppler shift frequency measurement by the aft transducer will be



Vv
α
α
(90 - α)
- v Cos α + Vv Sin α
v Cos α + Vv Sin α
Seabed

$$fr_a - ft = -2\ v\ ft\ Cos\ (\alpha + \beta) / c$$

$$\text{Thus } fr_f - fr_a = 2\ v\ ft\ [\ Cos\ (\alpha - \beta) + Cos\ (\alpha + \beta)\ ] / c$$

$$= 2\ v\ ft\ [\ Cos\ \alpha\ Cos\ \beta + Sin\ \alpha\ Sin\ \beta$$

$$+ Cos\ \alpha\ Cos\ \beta - Sin\ \alpha\ Sin\ \beta\ ] / c$$

$$= 2\ v\ ft\ (2\ Cos\ \alpha\ Cos\ \beta) / c$$

$$= 4\ v\ ft\ Cos\ \alpha\ Cos\ \beta / c$$

$$v = (fr_f - fr_a)\ c / 4\ ft\ Cos\ \alpha\ Cos\ \beta$$

Note

$$Cos\ (\alpha + \beta) = Cos\ \alpha\ Cos\ \beta - Sin\ \alpha\ Sin\ \beta$$

and $$Cos\ (\alpha - \beta) = Cos\ \alpha\ Cos\ \beta + Sin\ \alpha\ Sin\ \beta$$

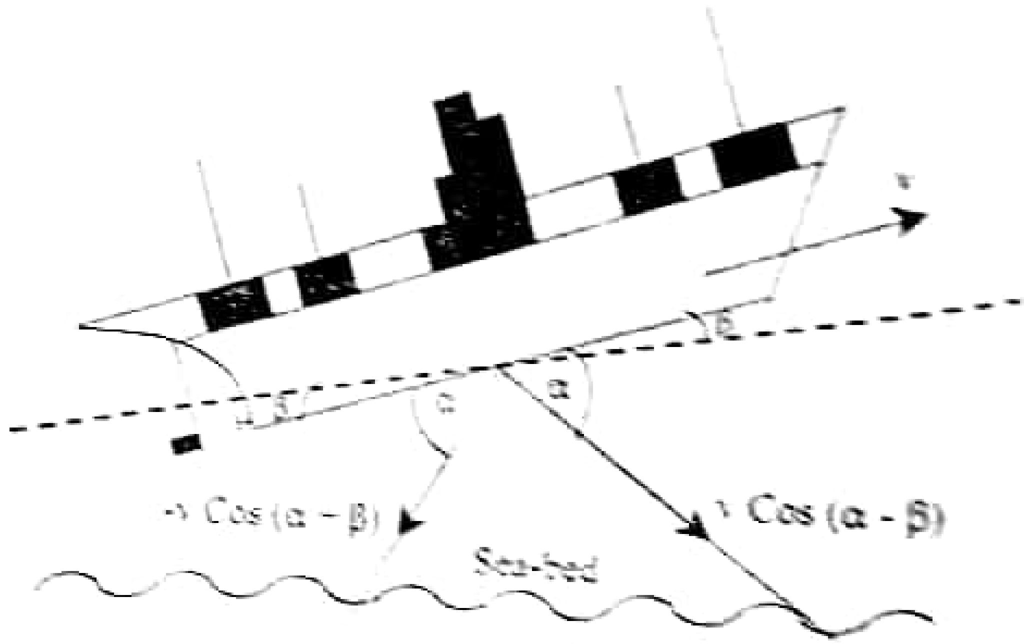


Figure 4
Ship trimmed- down by stern at angle β

The above formula gives the actual speed in trimmed condition while speed indicated is calculated by given formula

$$v = (fr_f - fr_a)\ c / 4\ ft\ Cos\ \alpha$$

Hence Actual speed = Indicated speed / Cos β.

- **When down by head**

When trimmed by head at angle β, the forward transducer is transmitting at angle (α + β) while the aft transducer is transmitting at angle (α- β) as shown in figure 5.

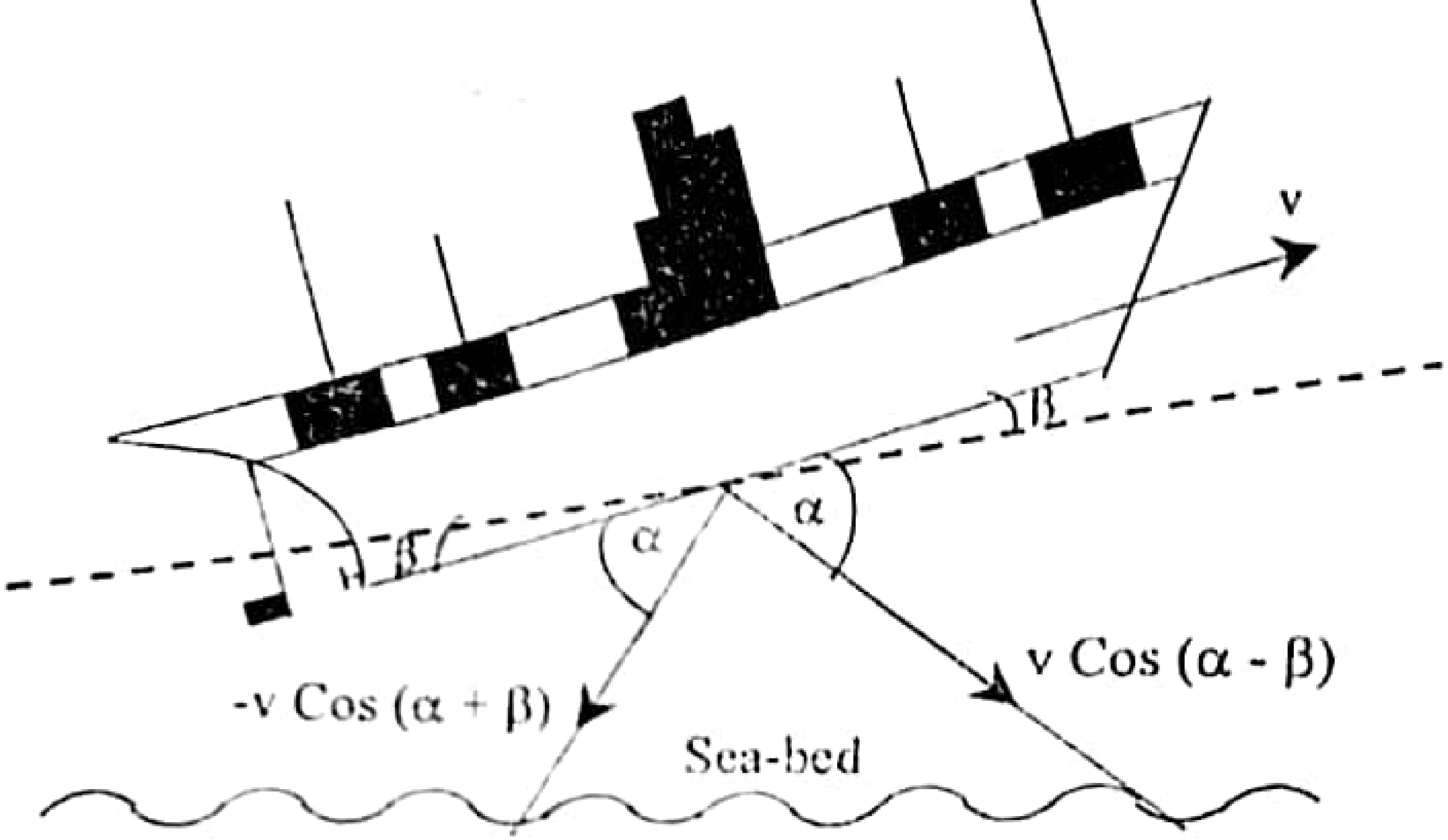


Figure 4

Ship trimmed- down by stern at angle β

واقعی

The above formula gives the actual speed in trimmed condition while the speed indicated is calculated by given formula

$$v = (fr_f - fr_a)\, c \,/\, 4\, ft \cos\alpha$$

Hence Actual speed = Indicated speed / Cos β. ***

- **When down by head**

When trimmed by head at angle β, the forward transducer is now transmitting at angle (α + β) while the aft transducer is transmitting at an angle (α- β) as shown in figure 5, hence

$$fr_f - ft = 2\,v\,ft\,Cos\,(\alpha + \beta)\,/\,c \quad \text{and}$$
$$fr_a - ft = -2\,v\,ft\,Cos\,(\alpha - \beta)\,/\,c$$
$$\text{Thus } fr_f \,.\, fr_a = 2\,v\,ft\,[\,Cos\,(\alpha + \beta) + Cos\,(\alpha - \beta)\,]\,/\,c$$
$$= 2\,v\,ft\,[\,Cos\,\alpha\,Cos\,\beta - Sin\,\alpha\,Sin\,\beta + Cos\,\alpha\,Cos\,\beta + Sin\,\alpha\,Sin\,\beta\,]\,/\,c$$
$$= 2\,v\,ft\,(2\,Cos\,\alpha\,Cos\,\beta)\,/\,c$$
$$= 4\,v\,ft\,Cos\,\alpha\,Cos\,\beta\,/\,c$$
$$v = (fr_f - fr_a)\,c\,/\,4\,ft\,Cos\,\alpha\,Cos\,\beta$$

Once again indicated speed is less than actual speed by factor of $1\,/\,Cos\,\beta$ i.e. whether down by head or down by stern,

Actual speed = Indicated speed / $Cos\,\beta$ **

Maximum trim permitted under Marpol Annex I Reg 13 is 1.5% of ship's length. Hence $\beta = Tan^{-1}\,1.5\,/100$, ***

$\beta = 0.86°$

and $Cos\,\beta = Cos\,0.86° = 0.9998874$.

Now if the indicated speed is 16 knots, the actual speed = 16 /0. 998874

= 16.001689 kts.

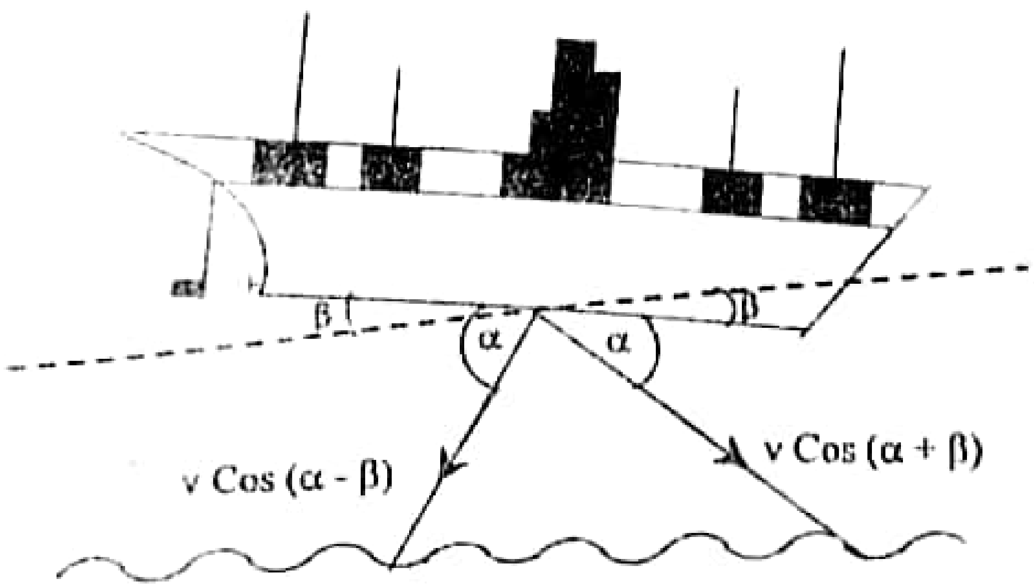
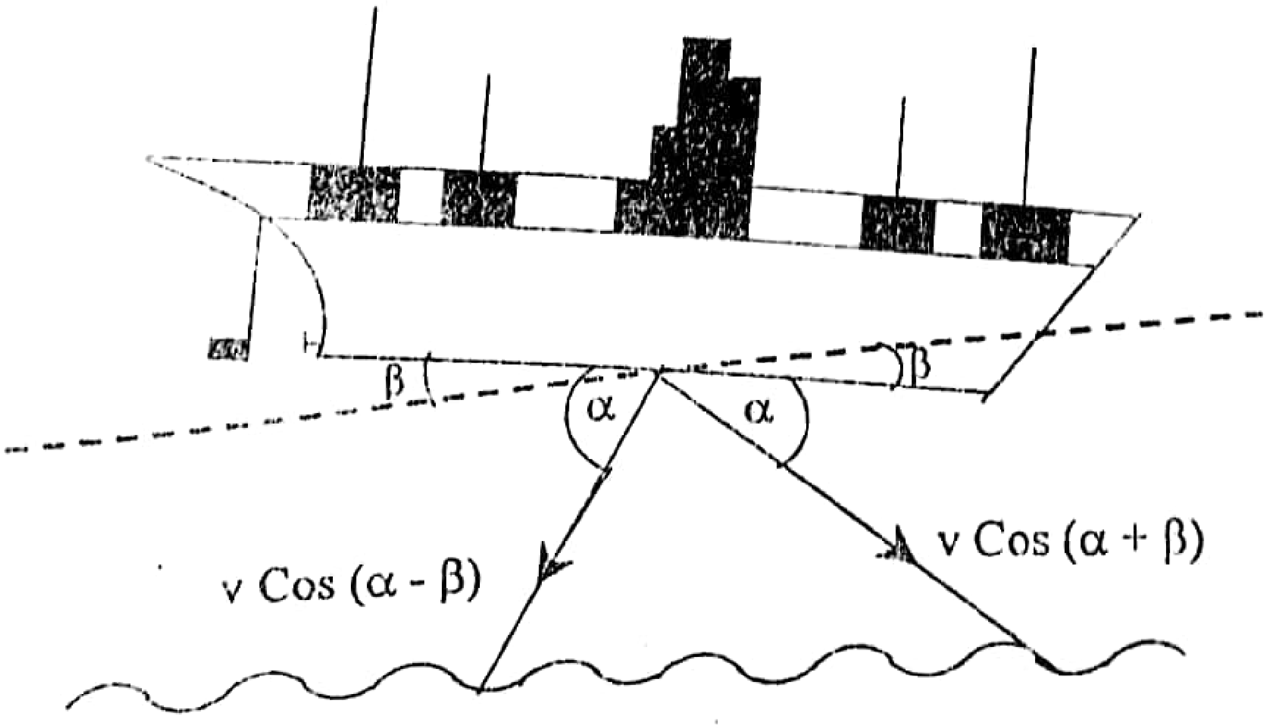


Figure 5
Ship trimmed-down by head at angle β


β
β
α
α
v Cos (α - β)
v Cos (α + β)

We notice that the difference is only in the third and fourth decimal places. In other words it is negligible difference. In fact this difference may not be indicated on the display, since the display shows only up to two decimal places. Note that change of trim does not effect the athwartships speed.

➤ **Pitching**

The effect of pitching is similar to a vessel with trim changing continuously. When the vessel is pitching, the indicated speed will fluctuate between actual speed and a value lower then the actual speed depending on the angle at which it is pitching. Pitching does not effect athwartships speed. **

➤ **List and rolling**

Effect of list on athwartships speed will be the same as the effect of trim on the forward and aft speed i.e.

Actual speed (ath) = Indicated Speed (ath) / Cos list

This is irrespective of the side to which the ship is listed. When the vessel is rolling, the indicated athwartship speed will fluctuate between the actual speed and the indicated lower speed worked out by the above formula depending on the angle of roll. List and rolling does not effect the fore and aft speed.

ERRORS

➤ Error in transducer orientation

The transducers should make a perfect angle of 60° with respect to the keel or else the speed indicated will be inaccurate.

➤ Error in oscillator frequency

The frequency generated by the oscillator must be accurate and constant, any deviation in the frequency will result in the speed indicated being in error.

➤ Error in propagation velocity of acoustic wave

The velocity of the acoustic wave at the temp of 16°C and salinity of 3.4% is 1505 m/sec, but generally it is taken as 1500 m/sec for calculation. This velocity changes with temperature, salinity or pressure. To compensate the error due to temperature variation, a thermistor (i.e. a resistance whose value changes with temperature) is mounted near the transducer and change in velocity of the acoustic wave through water from the standard value due to the change in seawater temperature is accounted for. In modern transducers the angle at which the beam is transmitted is controlled with the help of phase difference and the factor c / Cos α is not used in calculating V.

We notice that the difference is only in the third and fourth decimal places. In other words it is negligible difference. In fact this difference may not be indicated on the display, since the display shows only up to two decimal places. Note that change of trim does not effect the athwartships speed.

- **Pitching**

The effect of pitching is similar to a vessel with trim changing continuously. When the vessel is pitching, the indicated speed will fluctuate between actual speed and a value lower then the actual speed depending on the angle at which it is pitching. Pitching does not effect athwartships speed.

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Effect of list on athwartships speed will be the same as the effect of trim on the forward and aft speed i.e.

Actual speed (ath) = Indicated Speed (ath) / Cos list

This is irrespective of the side to which the ship is listed. When the vessel is rolling, the indicated athwartship speed will fluctuate between the actual speed and the indicated lower speed worked out by the above formula depending on the angle of roll. List and rolling does not effect the fore and aft speed.

➢ Errors due to ship's motion

During the interval between transmission and reception, the ship may marginally roll or pitch and thereby the angle of transmission and reception can change and for a two degree difference between the angle of transmission and reception, the net effect will be an error of 0.10% of the indicated speed which is marginal and can be neglected.

➢ Errors due to the effect of rolling and pitching

The effect of pitching will cause an error in the forward speed but it has no affect on the athwartship speed. Similarly rolling will cause an error in athwartship, but not in forward speed.

$$\text{Actual Speed} = \text{Indicated speed} / \cos\beta$$

Where β is the angle of pitching for forward speed and angle of roll in case of athwartship speed, e.g. if the ship is pitching at an angle of 10° and the indicated speed is 15 knots, then the

$$\text{Actual speed} = 15/\cos 10^{\circ}$$

$$\text{i.e. Actual speed} = 15.23 \text{ kts.}$$

This error will increase with angle of pitch i.e. in rough seas. The digital readout will fluctuate between the actual speed (i.e. at the instant when the pitch angle is zero) and a value lower than the actual speed (i.e. when the angle of pitch is maximum).

The athwartship speed assumes importance only at the time of berthing where the rolling is negligible and hence the above formula is generally used in case of forward speed only.

➢ Error due to inaccuracy in measurement of comparison frequency

The difference in the frequencies received by the forward and aft transducers must be measured accurately as any error in this will be directly reflected in the speed of the vessel.

➢ Error due to side lobe

When the side lobe reception dominates over the main beam reception, there will be an error in the speed indicated. This error is more pronounced on a sloppy bottom, where the side lobe will be reflected at a more favourable angle and will have path length less than the main beam.

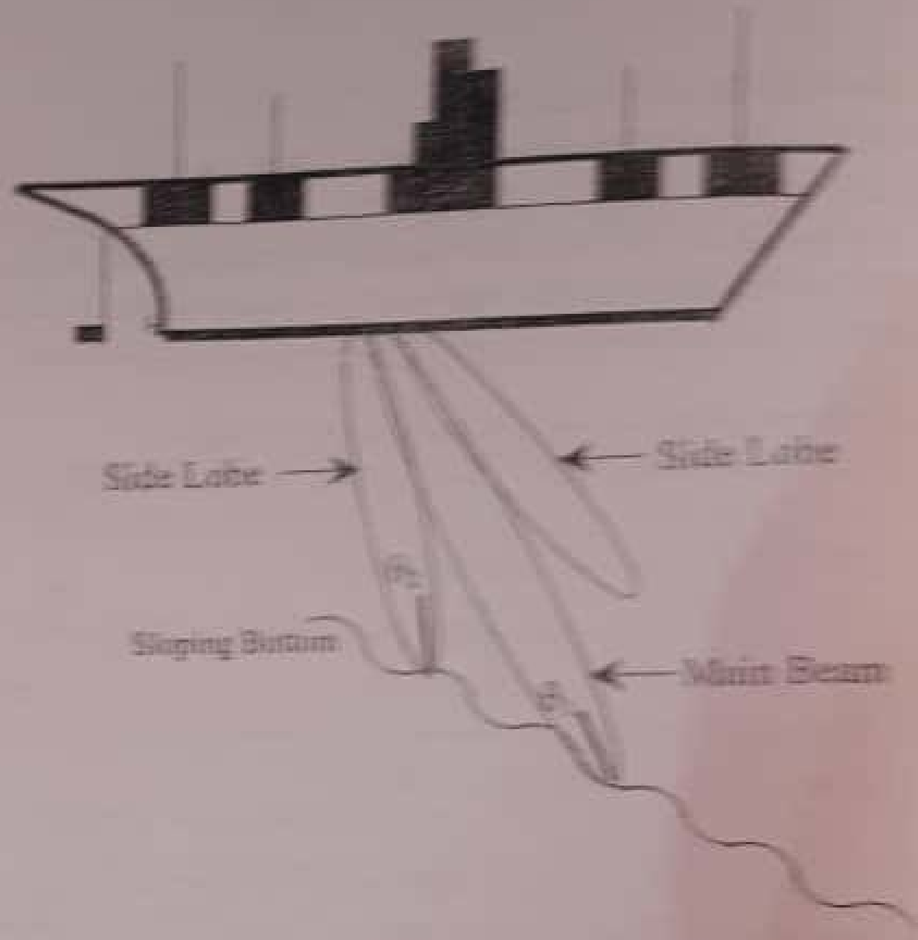


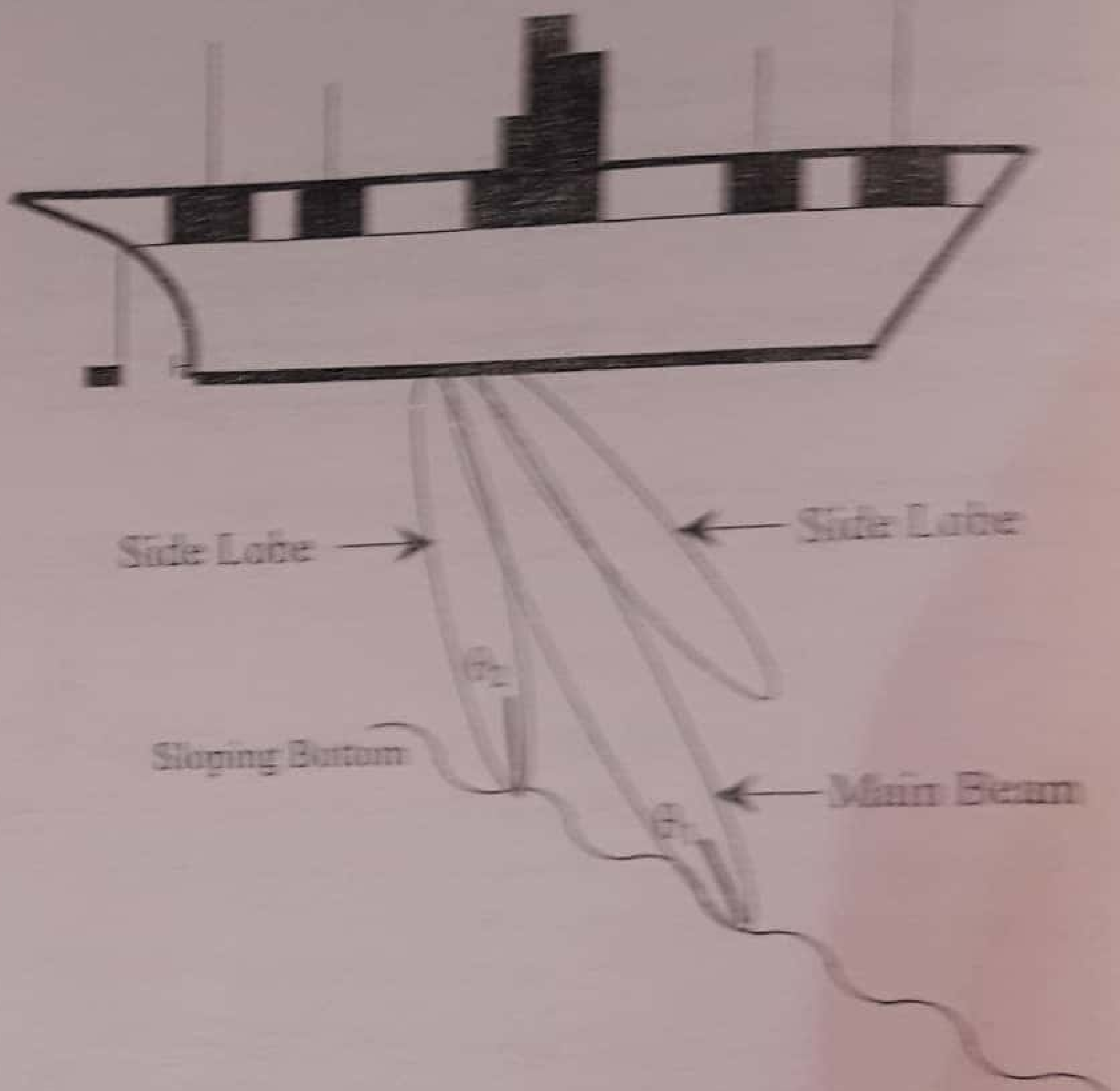
Figure 6
Side lobe error

This error cannot be eliminated with the help of Janus configuration and to reduce this error the beam of the transmitted acoustic wave is reduced. However a minimum beam width of 4 to 6° is required

CALIBRATION

It is very important for any instrument to be calibrated correctly before being used and in a Doppler log the calibration has to be done in two steps

- Firstly the zero on scale should be set correctly and this can be done and checked whenever the ship is berthed at a jetty or at anchor when the speed over ground is zero and
- The second is the scale calibration and should be done during sea trial when time taken to cover a measured mile is noted and the speed is calculated This calculated speed must match with the displayed reading and in case of any discrepancy between the two, the equipment can be adjusted. Once these two calibrations are done the Doppler log can be used effectively.


Side Lobe
Side Lobe
Sloping Bottom
Main Beam

This error cannot be eliminated with the help of Janus configuration and to reduce this error the beam of the transmitted acoustic wave is reduced. However a minimum beam width of 4 to 6° is required

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اختلاف
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