ANIMP
Multiphase Flow Engineering Section

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Unfortunately, both these types of instruments are of high cost and their performances are particularly oriented to a laboratory use.

Again with reference to Fig. 5, in Fig. 7 a procedure is shown where the measure of phase is again reduced to the measure of the amplitude of a microwave signal, this signal being now obtained by summing to the received signal a reference one which is a portion of the input signal to the antenna. We can easily show that, if received and reference are phase shifted of about 90 degree, the envelope of the resulting signal is a sufficiently linear function of the phase variations around the set point. The best phase condition can be obtained by suitably trimming the lengths of the cables relative to the recived and reference signals.

3.3) Experimental results

An experimental laboratory-scale set-up was implemented according to the measuring schema of Fig. 5. In Fig. 8 a view of the measuring apparatus is shown, relative to the case of attenuation measurement.

With the use of a shaker, a discrete flow of glass powder was otained inside a plexiglass tube with a square cross section. A horn antenna radiates a continuous microwave signal (frequency ≅ 20 GHz) which travels along a diameter of the tube and is received by the same antenna after being reflected by the opposite metallic plate. A directional coupler allows to detect the reflected wave whose amplitude, after a suitable amplification, is recorded, vs. time, on a chart recorder. The peack density of the suspension was estimated to be about 50 gr/dm^3.

In Fig. 9 an example of the recorded signal is reported.

The irregularities present in the signal between the absorption dips is partially due to the derivative effects of the high pass filter.

4. CONCLUSIONS

The use of a microwave sensor for real time and non intrusive measuring the density of a solid dielectric particles suspension in air was considered.

The propagation of an e. m. wave through the suspension was studied and the possibility of using for the purpose above both attenuation as phase shift information was theoretically proved.

With particular reference to the measure of the density of suspensions flowing inside a tube, as is the case of pneumatic transport lines, different implementation techniques were proposed, based on the use of a microwave signal, with frequency of tens of gigacicles per second, propagating along the diameter of the pipeline.

Preliminary experimental results obtained on a simple laboratory- scale model are reported.

Assuming that Uo has unitary amplitude and phase equal zero for t=0 at z=0, we have

$$Uo(z,t) = \exp(-jkz + j\omega t) \qquad (1)$$

where $\omega = 2\pi f$ and $k = 2\pi/\lambda$, with f and λ frequency and free-space wavelength of the em wave, respectively.

In a spherical reference (r, θ, φ), with the origin at O, the e.m. wave diffracted by the particle, evaluated at P, can be expressed as [1,2]

$$U = Uo(0,t)\, S(\theta, \varphi)\, \exp(-jkr)/(jkr) \qquad (2)$$

The function $S(\theta, \varphi)$, which is, generally, a complex function, is defined as the Amplitude Function (AF) of the scattering particle.

Let's now assume that the region with $|z| \le L/2$, $|x| \le D/2$, $|y| \le D/2$ is filled by an air suspension of dielectric particles, irradiated by a plane, uniform e.m. wave expressed by Eq. (1) (Fig. 2).

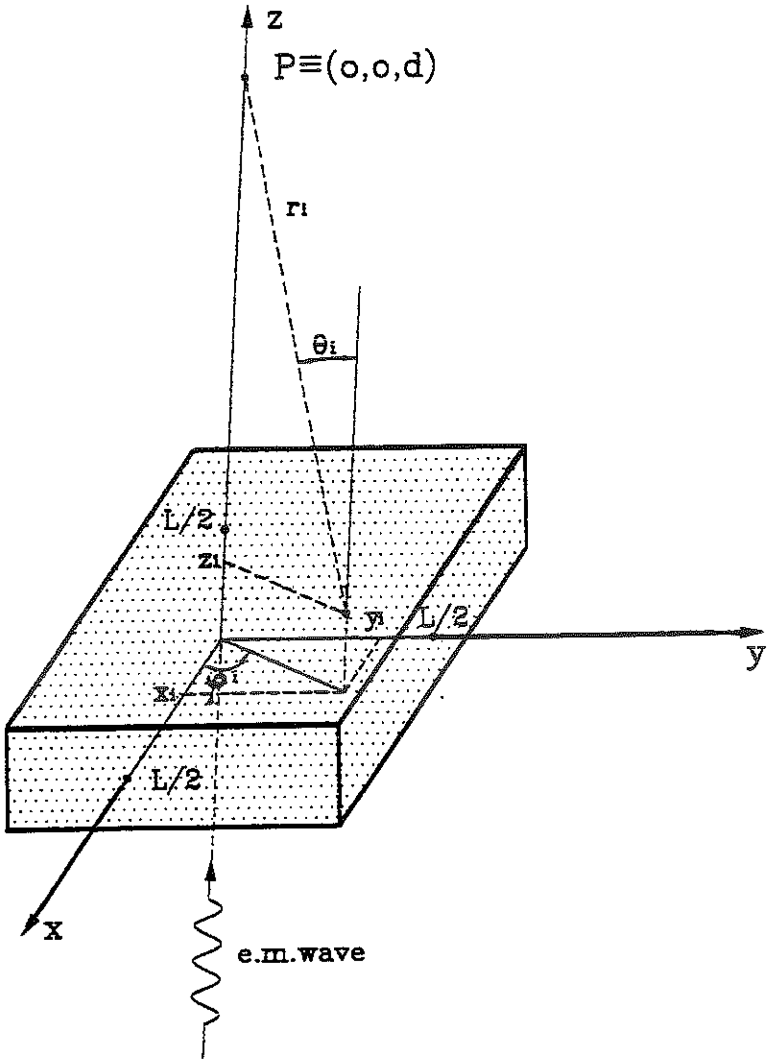

Fig.2

However, in the assumption that the distance d of P from the origin is such that the first Fresnel zone is inside the region $x| \le D/2$, $|y| \le D/2$, we can extend the integretion limits with respect to variables x and y from $-\infty$ to $+\infty$, and, for the case of $N(x,y,z)$ = Constant value = N, we obtain

$$U = NS(0)\exp(j\omega t-jkd)/(jk)\int_{-L/2}^{L/2}\iint_{\infty} \exp[-jk(x^2+y^2)]/(d-z)dxdydz \qquad (9)$$

By putting $Uo = \exp(j\omega t-jkd)$ = e.m. wave at P in the case where no particle is present, Eq. (9) becomes

$$U = NS(0)Uo\int_{-L/2}^{L/2}\iint_{\infty} \exp[-jk(x^2+y^2)]/(d-z)dxdydz \qquad (10)$$

Finally, taking into account that

$$\int_{-\infty}^{+\infty} \exp\{-ikx^2/[2(d-z)]\}dx = [2\pi(d-z)/(jk)]^{1/2} \qquad (11)$$

and that the whole e.m. wave U_T in P is the sum of Uo and U we obtain

$$U_T = Uo[1-2\pi/k^2NS(0)L] = Uo[1-\lambda^2/(2\pi)NS(0)L] \qquad (12)$$

It can be shown that [2], under the assumptions already considered, in the case of a vectorial polarized e.m. wave, Eq. (12), with reference to the e.m. electric field becomes

$$\mathbf{E}_T = \mathbf{Eo}[1-\lambda^2/(2\pi)NS(0)L] \qquad (13)$$

where $\mathbf{E}_T$ is the electric field in P resulting from the direct an the diffracted wave, and **Eo** is the electric field in P in the case of absence of particles.

Let'us now consider the case where the region $|z| \le L/2$ contains no particle, but is filled by a homogeneus medium with a refraction index m.

The electric field in P of an e.m. linearly polarized wave propagating along the z axis and coming from the z negative axis can be written as

$$\mathbf{E}_T = \exp[j\omega t - jkmL - jk(d-L)] \qquad (14)$$

where the further assumption was made that the reflections at the interfaces $z = -L/2$ and $z = L/2$ can be not considered ($|m|$ sufficiently near to the unit).

The electric field in P, in the absence of material, is $\mathbf{Eo} = \exp(j\omega t - jkd)$, so that Eq. (14) can be written as

$$\mathbf{E}_T = \mathbf{Eo}\exp[-jk(m-1)L] \cong \mathbf{Eo}[1-jk(m-1)L] \qquad (15)$$

By equating expression (15) and (13) we have

$$m = 1+\lambda^2/(j2\pi k)NS(0) \qquad (16)$$

measure of the attenuation and/or the phase shift of an e.m. wave which propagates along a diameter of the tube itself, according to the diagram of Fig. 3.

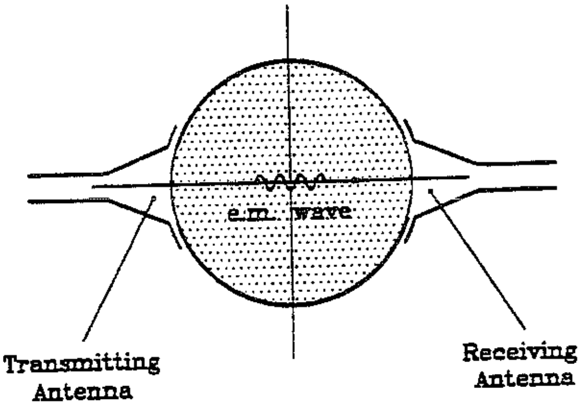

Fig.3

In the assumption that the diameter of the tube has a value of tens of centimeter, the use of an e.m. wave with a frequency of tens of gigacicles per second (20-30 GHz) is required in order to achieve a sufficiently directivity for the antennas with suitable sizes and to avoid near field influence. The use of e.m. waves with sufficiently high frequency also enhance the procedure sensitivity, as clearly proved by Eqs. (22 and (23).
Sensitivity can be further improved by using the particular measure configuration of Fig. 4 where a multiple propagation along the diameter of the tube is used.
The simplest way to implement a multiple (double) propagation along a diameter is schematically shown in Fig. 5 where the e.m. signal emitted by the antenna is reflected on the opposite region of the tube, is received by the same antenna and, finally, is available at the circulator output. In this case modification of the shape of the reflecting zone, opposite to the antenna, may be required to improve the reflection itself.

3.1) Attenuation measurement

Even in the subcentimetric wavelength range, attenuation measurements can be implemented using microwave componenets of not excessive cost and with the possibility of being used in industrial environment.
In Fig. 6 a measuring set up for this purpose is shown, with particular reference to the case of Fig. 5. The schema can be easily modified to be adapted to the cases of Fig. 3 and 4.
The density of suspension g is obtained by comparing the signals levels measured when the particles are flowing in the tube and in the case of empty tube.

3.2- Phase measurements

At frequencies of tens of GHz, phase measurements with suitable sensitivity are not so easily obtained as attenuation measurements. A class of commercially available instruments which can measure phase shifts with good sensitivity are Vectorial Analyzers or, with lower performances, Vectorial Voltmeters.

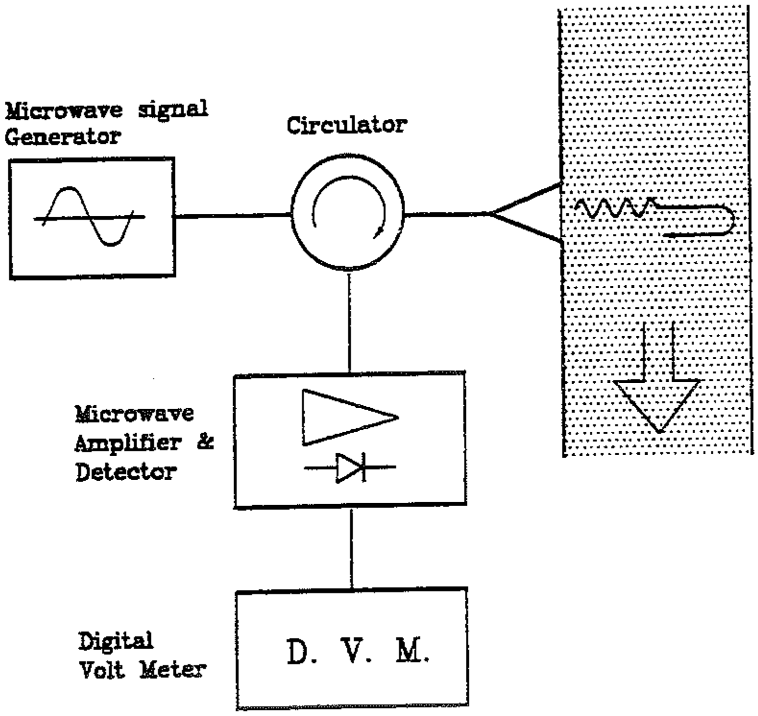
Microwave signal
Generator
Circulator
Microwave
Amplifier &
Detector
Digital
Volt Meter
D. V. M.

Fig.6

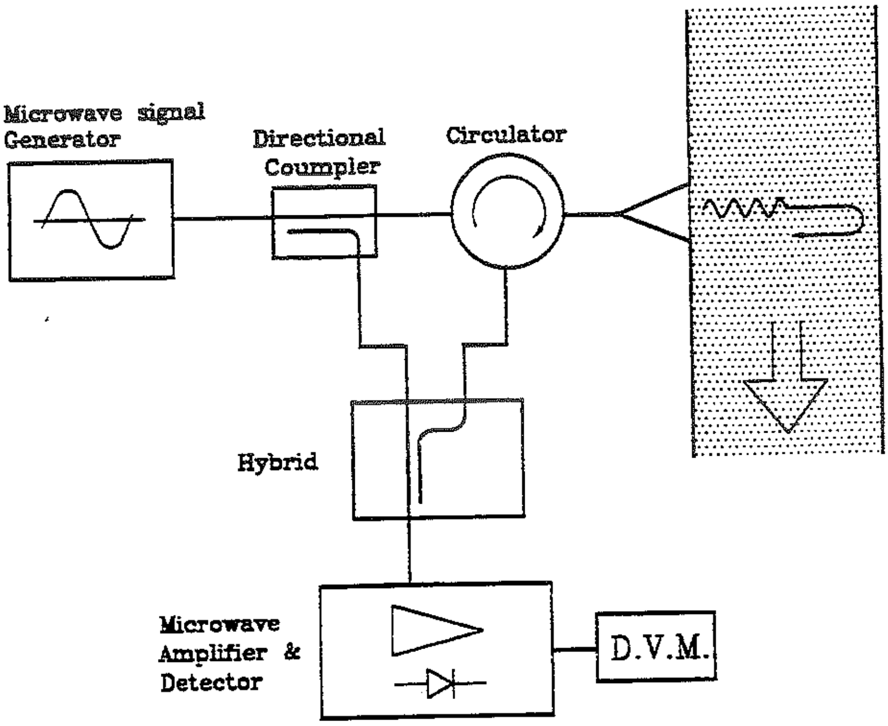
Microwave signal
Generator
Directional
Coumpler
Circulator
Hybrid
Microwave
Amplifier &
Detector
D.V.M.

Fig.7

NEW MICROWAVE SENSOR FOR NON-INVASIVE DENSITY MEASUREMENT OF DIELECTRIC PARTICLES -AIR SUSPENSION IN PNEUMATIC TRANSPORT LINES

M. Bramanti
Istituto di Elaborazione della Informazione of CNR
via Santa Maria, 46, 56100 Pisa (Italy)
Tel.:+39.50.593472; FAX: +39.50554342
Email: bramanti@iei.pi.cnr.it

Abstract

The use of pneumatic lines to transport solid materials in the form of particulate suspension is a well known and common procedure in industrial field. In these cases the problem exists of measuring the density of the suspension, the methods being generally required to be real time and non-invasive with respect to the line itself.
A class of the techiques proposed for the purpose above are based on the use of electromagnetic fields or waves in different frequency ranges.
Here a density sensor is proposed where a microwave signal , with frequency of about 20 GHz, has a multiple interaction with the suspension under test.
By a theoretical analysis of the diffraction phenomena due to the interaction of the electromagnetic wave with the particles it is proved that both real as imaginary part of the propagation constant along the diameter of the pipe line is a function of the suspension density. Successively, suitable implementation solutions are suggested and experimental results, obtained from a laboratory scale model, are reported.

Sommario

L'uso di linee per il trasporto pneumatico di particolati è molto diffuso in diverse applicazioni industriali. In questi casi è tuttora aperto il problema di trovare tecniche idonee alla misura della densità della sospensione con procedure che siano real-time e non invasive rispetto alla linea di trasporto medesima.
Fra le varie soluzioni proposte allo scopo, molte sono basate su tecniche di tipo elettromagnetico, con differenti range di frequenza del segnale di misura.
Nel presente lavoro si propone un sensore di densità basato sulla interazione della sospensione con un segnale a microonde, nella gamma dei 20 GHz, che si propaga lungo un diametro della condotta sotto test.
A partire dall'analisi teorica dei fenomeni di diffrazione connessi all'interazione dell'onda elettromagnetica con le particelle della sospensione, si dimostra che sia la parte reale che la parte immaginaria della costante di propagazione all'interno della sospensione dipendono dalla densità della medesima. Successivamente, vengono proposte soluzioni implementative della procedura e, infine, si riportano i risultati sperimentali ottenuti su un modello di laboratorio.

1. INTRODUCTION

The use of pneumatic lines to transport solid materials in the form of a particulate suspension is a well known and commonly used procedure in industrial field.