Much work must be done to combine all these measurements into an over-all concept of operator performance. However, through experimentation and research, this problem may be solved in the near future, for UNOPAR now makes measurements that could not even be roughly approximated in the past.

Other problems dealing with work, or with what a human being does, may be solved with the aid of UNOPAR. A brief review of some possibilities will show the widespread adaptability of the measurements. [For a complete discussion of all aspects of the UNOPAR and its potential uses, see G. Nadler, *Motion and Time Study* (McGraw-Hill, New York, 1955), pp. 417–428.] The instrument may not be capable of summarily solving all problems outlined in subsequent paragraphs, but at least much light may be shed on these problems.

Let it be assumed that a time standard is established for a definite method and that it is essential to accurately describe the method. Many disputes arise today because of the use of qualitative methods of description. It is difficult to determine when a change in time standards is fair if there are no ways of computing values of percentage variations of methods. Quantitative measurements from UNOPAR may help to establish a procedure for detecting changes in method.

If the permanent record of displacement and position gives new information about motions, motion patterns, and motion paths, better decisions can be made about the correct motions for an operation as well as about the correct sequence of these motions.

Frequently, two operators, using what is considered to be the same method, differ considerably in performance. An accurate measurement of their motions may disclose subtle differences in performance that are not readily observable. With the information about individuals and individual differences obtained by using UNOPAR, it may be possible to train poor operators to improve their performances.

Time units on the UNOPAR records are as small as 0.000133 minute, measured on a recorder tape moving at a speed of 125 millimeters per second at 1-millimeter intervals. Even smaller time units can be obtained. When this level of accuracy is not needed, a slower speed can be used. Measurement of the elapsed time required to complete a motion or an operation is a great deal more accurate than usual timing procedures, especially since full actual motions are recorded, not just end-points determined through an individual's reaction time and other errors.

The difficulty of an operation affects the pace of an operator. Because difficulty and pace are interrelated, UNOPAR can help obtain accurate information about difficulty.

There are many standard data systems (compilation of past standard time information for application purposes without direct study) in use today. There is some controversy about the validity of these systems. Because times for motions or groups of motions form the bases for these systems, UNOPAR can check into their assumptions.

Even if there were no other advantages to be gained through the use of UNOPAR, one of the most readily apparent is that exact information about each and every motion of each cycle is recorded, whereas other procedures of motion and time study or work simplification and measurement obtain only over-all information. The ability to provide specific information is a basic requirement for any good measurement procedure.

However, the use of UNOPAR will not be restricted to industrial engineering alone. As is pointed out in a foregoing section, measurement of human performance is needed in other areas, such as psychology, physiology, sociology, biomechanics, education, and physical education. Within the near future, UNOPAR should help solve many of the problems in each of these areas by providing accurate information about motions and performance.

With this objective information, management and labor should benefit through more accurate information for all the areas in which time standards are important.

It is important to warn that UNOPAR has not been fully developed and that, when it is, it may not be capable of everything expected of it. However, it represents such a radical change in the concept of measurement of human performance that we think it can be expected to revolutionize many aspects of industrial engineering. We believe that the information available from UNOPAR is so much more accurate than that available from other procedures or techniques that much more can be learned about the performance of a human being than ever before.

Phase Microscopy 1954–56

Oscar W. Richards

Phase microscopy has become a recognized standard method. Few publications now refer to it in the title, and a complete listing of papers is no longer possible. Some of the uses of phase microscopy in the first 2 years of the second decade since we demonstrated the first American instrument (*1*) are summarized here as well as a few papers missed in the preview review (*2*). Details on the function and use of the instrument in various fields are available (*2, 3*).

General, Theory, and Instruments

While the previous review was in press, Wilska (*4*) described the new Reichert Anoptral phase microscope, which is unique in using a less reflecting material than evaporated metal for the diffraction plate. Bright contrast is used so that differences in the refractive power of the specimen are better revealed (*5*). The outside diameter of the diffraction plate is made larger for increased resolution. The image is slightly yellowish, less harsh, has less glare, and photographs well, as is shown in the varied photomicrographs of Schüller (*6*).

A bibliography has been published by the firm of Winkel (*7*), Fröhlich has summarized some German and Swiss work (*8*), and information on the theory and use of phase is included in the symposium reported by Françon (*9*). General discussions in Dutch have appeared by Bok (*10*) and Bogaerdti (*11*). Czerny (*12*) expresses amazement that phase was not discovered between Abbe and Zernike, apparently unaware of the work of Bratucheck and of Conrady and Rheinberg (*13*). Zernike (*14*) tells how he discovered phase about 1930, and some general and medical applications are mentioned by Crossmon (*15*).

Wolter (*16*) summarizes much of his work and relates phase to *schlieren* and other methods, and Barer (*17*) summa-

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rizes his vector theory of phase microscopy along with some useful historical information. The intensity distribution of the light in the image of a rectangular object for commercial phase microscopes is calculated by Schmidt (*18*), and optimal values of retardation and size of annulus are deduced and confirmed by experimental measurements. A wedge-shaped collodion test object is proposed by Menzel (*19*) for phase contrast. Precision absolute phase measurements are reported by Fleischmann and Wegener (*20*). Kahn (*21*) derives conditions from Maxwell's equations which indicate that no restriction need be placed on the shape of the object to be examined. Improved phase and interference microscopy are discussed by Wolter (*22*), who uses polarization methods to measure phase and amplitude changes. Thus, a quantitative phase microscopy may become possible. Räntsch has tested two methods for obtaining maximal phase contrast and, after comparing amplitude and phase effects, concludes that variable amplitude and a 90° phase shift would give best contrast in a variable phase microscope (*23*).

The Zeiss-Winkel phase accessories are described by Flügge (*24*), and Kawiak (*25*) describes Zeiss equipment in Polish. Matthews (*26*) uses a hollow-cone method for illuminating the phase plate, which can be changed to darkfield illumination.

The patent literature has increased considerably. Bennett (*27*) has a patent on a method for variable phase microscopy. Françon *et al.* (*28*) have included phase in a catoptric system. Heine (*29*) obtains colored phase contrast by using colors in the conjugate and complimentary areas, and L. Leitz (*30*) by means of a tricolor filter ahead of a darkfield condenser and the use of a tapered diffraction plate. Kavanagh (*31*) patented a method using separate paths for the deviated and undeviated light as means for varying the phase contrast. E. Leitz G. m. b. H. (*32*) have a patent for polarized light in a phase vertical illuminator, and Locquin (*33*) has one for variable phase together with color phase contrast. The variation in the color of the light is accomplished by tilting an interference filter. Menzies (*34*) has a phase system using alternate sectors of opaque and transparent material. Variable phase patents include a wedge system of Osterberg (*35*) and Bennett and Kavanagh's system combining an iris, patch stop, and an auxiliary lens (*36*).

A compact photomicrographic apparatus with electronic flash illumination is described by Jarrett (*37*) for phase pictures of moving specimens. Wied (*38*) combines a Micro Ibso attachment with a Linhof Technica camera having a Polaroid back in order to obtain rapidly finished pictures with the phase microscope. A flexible motion picture installation with electronic timing is described by Robineaux (*39*).

Phase Combined with Other Methods of Microscopy

The increasing tendency to use several methods of microscopy on appropriate problems is further noted. Some examples are cited here, and others mentioned under their appropriate topics. Wolter discusses phase and interference microscopy (*40*).

Locquin (*41*) appears to be the first to use phase methods in an electron microscope; he achieves the equivalent of a B- phase plate that reveals contrast with changes of specimen thickness. Combinations of phase and electron microscopy are used by Becher and Hoegen (*42*) to examine the action of hyaluronidase on individual cells. Borysko and Sapranauskas (*43*) combine the methods for the study of tissue cultures with time-lapse cinephotomicrographic checks. *Penicillium* is examined with phase and electron microscopes by Bringmann (*44*). De *et al.* (*45*) use both microscopes to study the nuclear apparatus of *Escherichia coli*. Movements of the centrosome are followed, as well as the change in contrast of the parts of the cells. Electron and phase instruments are used by Odor (*46*) to examine rat mesothelium, by Weinreb and Harman (*47*) for mitochondria, by Man'i (*48*) to investigate hemolysis, by Hodge (*49*) on dipteran flight muscles, by De Marsh and Kautz (*50*) on sternal biopsy cells, and by Hartroft (*51*) on renal juxtaglomerular cells. A new type of contrast, called interchromatic contrast by Locquin (*52*), is obtained with the electron microscope and is partly phase and partly new.

Phase and fluorescence microscopy are combined in a thorough study of the developing tooth by Hals (*53*). Mellors *et al.* (*54*) use fluorescence microscopy to locate antibodies in tissues and phase for detailed study. Phase microscopy is used by Krueger (*55*) to orient cellular material for ultraviolet absorption studies of salivary gland chromosomes.

General Methods

Phase microscopy is reported to be useful in the study of thick (30 to 80 microns) sections of injection preparations (Kleiss, *56*). Spodograms reveal more detail with phase than they do with ordinary microscopy, according to Godlewski (*57*). Haselmann *et al.* (*58*) describe a stage for holding a mouse for studies of secretion in the viscera and pancreas.

A microculture cell for growing bacteria has been devised by Devignat (*59*) and a perfusion chamber by Schwöbel (*60*), both for use with the phase microscope.

Lowenthal (*61*) reports that television phase microscopy gives added contrast and is useful for the examination of living leucocytes, and Hinselmann (*62*) uses television phase culposcopy.

Barer and Joseph (*63*) provide details on the theory and use of phase microrefractometry for measuring the refractive index of components of living cells. They match the index against a standard serum albumen solution, either directly, or by proportions of cells in a population showing the reversal in contrast. Dry and wet weights may be calculated from the index data, and when they are used with the interference microscope, some interchecking is possible. Ingelstam (*64*) applies and extends this new branch of phase microscopy. Gelatin is recommended as a reference mounting medium by Müller (*65*), for 8- to 80-percent solutions have refractive indices from 1.350 to 1.421.

The change of appearance of a detail from bright to dark contrast as the refractive index of the surround is greater or less than the detail (*3*) provides information on the uniformity of materials and the purity of isolates (*55, 66*).

Mounting media that may be useful in phase microscopy are Ferrari's (*67*) cumarone-indene resin (*n*, 1,650); Fleming's (*68*) improved Naphthrax; Salmon's (*69*) polyvinyl mixture (*n*, 1.399); Spurr's (*70*) polyvinyl alcohol-cadmium mixture (*n*, 1.467 to 1.6); and cellulose-caprate (*n*, 1.487), which sets rapidly, according to Lillie and Henson (*71*). Meyrowitz (*72*) has classified media of 1.74 and higher indices.

Motion Pictures

Phase cinephotomicrographs are reported by Pulvertaft (*73*) for medical applications; by Barski *et al.* (*74*) on cellular lesions produced by polio virus *in vitro*; by Gey *et al.* (*75*) on the plasma gell layer on normal and cancer cells; by Harman (*76*) on contracting skeletal muscle fibers; by Nakai (*77*) on tissue cultures of dorsal root ganglia; by Taylor and Gerstner (*78*) on the injurious effects of freezing tissue-culture cells; by Bessis (*79*) on immunohematology; by Pomerat *et al.* (*80*) on cell dynamics; by Pomerat and Lefeber (*81*) on the HeLa cell; by Blandau *et al.* (*82*) on movements of polymorphonuclear blood cells; and by Kramis and Hoyer (*83*) on changes in kidney cells from virus infection.

Microorganisms

Mason and Powelson (*84*) discovered more detail within bacteria immersed in

20- to 35-percent gelatin and propose this as a new technique (see also *3, 55, 63–66*), and Müller (*65*) uses gelatin mounting medium for yeast. Phase microscopy gives more information and better diagnosis on stained flagellae than other methods, according to Burcik and Plankenhorn (*85*). Phase is used by Harold and Stanier (*86*) in the study of *Leucothrix* and *Thiothrix*. Beakley and Williams (*87*) describe spore formation in *Bacillus subtilis* and *Bacillus mycoides* and Keigler and Smith (*88*) found more detail with phase in the spores of *Bacillus cereus* after enzyme cytolysis. Pleomorphism of pleuropneumonia bacteria is investigated by von Prittwitz and Gaffron (*89*). Schnauder (*90*) describes the L-phase changes of *Salmonella* on liquid and semisolid media, and Bartman and Höpken (*91*) give similar information for pneumonia organisms after release by penicillin (*92*).

Phase microscopy is used by Ito (*93*) in the analysis of the life-history of *Bacillus aneurinolyticus,* a thiamine-decomposing bacterium isolated from human feces. Poetschke *et al.* (*94*) use phase microscopy to examine stained tuberculosis bacteria, and von Karger (*95*) found phase microscopy and Ziehl-Neelsen staining both less efficient than fluorescence microscopy for locating tuberculosis bacteria. Electron and phase microscopy are used by Gupta and Viswanathan (*96*) to elucidate the effects of chemicals on tubercle bacilli. Cortelyou *et al.* (*97*) describe the degenerative changes in the nuclei of *Escherichia coli* damaged by ultraviolet radiation.

Phase microscopy is used by Herzberg and Bommer (*98*) and by Stoeckenius (*99*) for the examination of vaccinia virus. Differentiation of virus inclusion bodies in insects described by Vago (*100*) is useful in diagnosis.

The nucleus of the polyploid yeast cell is examined by Mundkur (*101*) with phase and ultraviolet microscopy using frozen-dried material (see also *65*). Moeschlin *et al.* (*102*) suggest that the plasma cells form the specific antibodies rather than the lymphocytes (see also *54*).

Mites and Eels

Baker and Wharton's (*103*) monograph on the *Acarina* shows the phase microscope to be helpful in the study of mites. Using the phase microscope, Luft (*104*) finds an array of perpendicular rodlets resembling a brush border at the anterior and posterior surfaces of the electroplax of the electric eel.

Cytological Techniques

The phase microscope is used by Bloom *et al.* (*105*) and by Haselmann (*106*) in the evaluation of freeze-drying as a preparation method. Less structurally damaging changes seem to accompany this method than other methods of cell and tissue fixation. Motion pictures are used by Haselmann (*107*) for the study of fixation changes. Borysko (*108*) reports on the gross changes that occur in the preparation of cells for thin sectioning and methacrylate.

Mitochondria are examined by Harman (*109*), Kaltenbach and Harman (*110*), Bierling (*111*), and Elster and Hoppe (*112*). The Royal Microscopical Society published a symposium on the Golgi apparatus (*113*); although evidence from phase microscopy was helpful, the Golgi question remains unsolved. Sorokin (*114*) reports on filaments formed in the cytoplasm of lettuce epidermal cells under anaerobic conditions. Haselmann (*115*) continues on the analysis of collagen and de Brux and de Boistesselin (*116*) tell of the action of hormones on the collagen fibers. Palay and Palade (*117*) describe the organization of Nissl bodies and the fine structure of neurons, and Kotilainen and Wilska (*118*), on examining sciatic nerves with Anoptral phase contrast, cast some doubts on the reality of the nodes of Ranvier as they can be formed by manipulation. Nissl substance of chick embryo spinal ganglia is studied with phase and ultraviolet photography by Deitch and Murray (*119*).

As the means for disrupting cells for the isolation of parts improve, the phase microscope is used more often for checking the procedures—for example, Denues (*120*) uses phase to assess cell destruction in the isolation of chromosomes, and Mawson and Fischer (*121*) examined semen for aspermia before chemical analysis. When some of a homogenate preparation is put into 30-percent plasma albumin, according to Barer *et al.* (*122*), it is possible to distinguish living cells from nuclei because of the lower refractive index of cytoplasm, which may be present either with cell preparations or small lymphocytes. Brown (*123*) differentiates thymus nuclear fractions with phase microscopy, using an alkaline 0.25*M* sucrose solution and serum albumin.

General Histology

Phase microscopy in histology is reported by Linz (*124*) on the surface epithelium of liver; by Vago (*125*) on the structure of the guinea pig organ of Corti; by Pagani (*126*) and by Garzino (*127*) on fibers in the lens of the eye; by Bandmann and Kipfer (*128*) on nerve fibers; by Weddell *et al.* (*129*) on mammalian skin nerve endings; and by Batchelor and Pate (*130*) on the formation of elastic tissue in grafted aortic segments. Garzino (*127*) finds the phase microscope a useful link between observation with the biomicroscope and histology, since artifacts, owing to fixing and staining, are avoided.

Blood and Hematology

Franke's (*131*) well-illustrated little book includes brief descriptions and phase photomicrographs of many blood cells. Leukocyte locomotion is investigated by Kosenow (*132*) and leukocyte phagocytosis of *Streptococcus pyogenes* by Daglia (*133*). Bessis (*134*) is relating the structure of living blood cells seen with phase with that seen in the electron microscope. He reports that phase microscopy reveals detail better than stained preparations and that it aids in differentiating between monocytic leukemia and some monoblastic, or lymphocytic leukemias. Jeschal (*135*) finds little difference between leukemic cells and normal lymphocytes. The diagnostic differences seen with phase between atypical myeloblasts and lymphoblasts are described by Brausil (*136*), who believes also that the phase microscope shows details in living cells that cannot always be identified in fixed smears. Phase microscopy has advantages for blood counting in dermatology, according to Merklen and Cottenot (*137*). Ahlhorn (*138*) reports that phase is more precise than Fenio's dilution method for thrombocytes. Siering (*139*) uses phase for counting reticulocytes, and Berman *et al.* (*140*) use it for platelet counting in the hamster.

Unstained and supervitally stained living blood and bone marrow cells are described as seen with the phase microscope by Ackerman and Bellios (*141*). The affects of adrenalin and acetylcholine are examined on living leukocytes by Seitz (*142*). Although anti-Rh serum produces little specific hemolysis, it can be detected with the phase microscope, according to Ballowitz and Ballowitz (*143*). Klausewitz (*144*) reports cytodiagnostic studies of amphibian living blood and lymph cells, and Altman and Grundmann (*145*) describe nuclear structure of human leucocytes. P-amino salicylic acid cytochemistry of erythroblasts concerns Astaldi *et al.* (*146*), and Czerski and Pawelski (*147*) find that megaloblasts in Addisonian anemia show an increase in the chondrion neutral red vacuoles and sudanophilic bodies compared to normal erythroblasts. Man'i (*148*) examines hemolysis in a special chamber with a collodion membrane to separate the blood cells from a flowing dialyzing medium.

Embryology

The phase microscope, according to Dan (*148*), shows a filament produced by the acrosome of the starfish sperma-

tozoon, which forms the fertilization cone when in contact with the egg jelly. Cytoplasmic inclusions in spermatocytes and neurons of *Helix* are studied by Roque (*149*) with phase and interference microscopes. Oettlé (*150*) observes morphologic changes in human spermatozoa after ejaculation, and Shettles (*151*) reports that the fallopian tube mucosa secretes an enzyme that is believed to facilitate fertilization by denuding the human ovum. The form and migration of embryonic pigment cells in a special flat tissue culture cell are observed by Algard (*152*).

Medical Applications

General summaries of the advantages in phase microscopy in medicine include: Fritze and Strufe (*153*), Poetschke (*154*), Zinser (*155*) and Fröhlich (*156*). Yamaguchi (*157*) recommends the phase microscope for the examination of the cutting edges of scalpels. Suchowsky (*158*) states advantages of phase in the study of diabetes and kidney pathology. Bommer (*159*) uses phase to find *Trichromonas vaganalis*, and Silva-Insunza and Coutts (*160*) use it to find trypanosomes. Damage to mouse spleen from radiation is shown by Scherer and Wichmann (*161*). Hofmann (*162*) finds phase helpful in the histological evaluation of ascites cells with respect to cysteine protection against radiation.

Phase microscopy is becoming popular for the diagnosis of fresh, exfoliated vaginal cells. Maggipinto and Milani (*163*) can identify and classify the cells by phase as well as with the Papanicolaou staining. The acidophilic index is lost, but there is a gain in the morphologic detail seen. Runge *et al.* (*164*) use phase in the polyclinic, and Wied (*165*) urges that gynecologists look at fresh material immediately to determine the normals and send only the doubtful and abnormal preparations to the laboratory.

The general application of the phase microscope to the study of tumors is summarized by Albertini (*166*). His Tyrofusine AK method allows the study of fresh material and facilitates distinguishing between normal and tumor cells. Phase microscopy is also favored in tumor diagnosis in Albertini's (*167*) monograph. Bright-contrast phase is used by Gey *et al.* (*168*) in the study of normal and malignant cell tissue cultures. Hirsch and Hager (*169*) report that placing frozen sections of brain tissue in methylglycol provides suitable contrast so that brain tumors can easily be found with the phase microscope. Central nervous system tumors may be examined and graded during an operation on the brain as an aid to proper operative procedure (Calvo, *170*). Riegel (*171*) believes that the phase microscope is the optimal method for the diagnosis of bronchial carcinomas and provides a list of some 20 diagnostic criteria. Sternal marrow puctures may reveal tumors when they are examined with the phase microscope (Jeschal, *172*).

Industrial

The use of the phase microscope in metallography and in mineralogy is summarized by Mitsche (*173*), and Beyer (*174*) discusses vertical phase illumination of metal surfaces. Mott (*175*) observes lightly etched, single crystal cleavage faces of multiphase alloys. A phase telescope with a slit diffraction plate is used by Saunders and Smith (*176*) in the examination of flames. Claver and Merz (*177*) report the examination of styrene-rubber polyblends with phase, and Wigman *et al.* (*178*) have prepared standard photomicrographs of starch granules with the aid of high contrast, bright and dark-contrast phase objectives.

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Design Study of a Megacurie Source

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Now that power reactors are in the design and construction stage, it is interesting to note that many of these reactors can economically produce megacurie amounts of cobalt-60. To get a feeling for the economic feasibility of such a scheme, consider the case of a reactor generating 500 megawatts of heat power. Each watt corresponds roughly to 3×10^{10} fissions per second, and each fission will release about 2.5 neutrons, one of which must be spent in continuing the chain reaction while the others are absorbed in the system. Allowing one of these latter neutrons to be captured in cobalt-59 will produce 3×10^{10} atoms of cobalt-60 per second, per watt, or, utilizing only 2 percent of the power of the reactor to be used in producing cobalt-60, there will have been produced

$$(10\times10^{6}\ \mathrm{w})\left(3\times10^{10}\ \frac{\text{atoms Co}^{60}}{\text{sec}}\right)\cdot\left(\frac{0.693}{5.2\ \text{yr}\times3.17\times10^{7}\ \frac{\text{sec}}{\text{yr}}\times3.7\times10^{10}\ \frac{d}{\text{sec c}}}\right)\times3.17\times10^{7}\ \frac{\text{sec}}{\text{yr}}=$$

$$1\times10^{6}\ \text{curie of cobalt 60/yr}$$

The cobalt can so be placed in the reactor that it will actually improve upon, rather than hinder, the efficiency of heat removal. For instance, cobalt can be used for the control rods of the reactor; it can also be used in flattening positions in the reactor; that is, it can be placed in such positions that the neutron flux distribution will be flattened, thus making the temperature distribution more uniform throughout the system and improving on the efficiency of heat removal; finally, cobalt can be put into peripheral positions in the reactor where it will have little effect on the flux distribution but will catch neutrons that ordinarily would have been lost to the thermal shield—thus the duty for the secondary cooling system on the thermal shield could be reduced and more heat could be directed to the power cycle.

At any rate, it is feasible in many power reactor designs to incorporate space for cobalt in such positions that the neutrons absorbed are essentially free, and the true costs involved are the cost of fabricating the cobalt pieces and the infrequent operational cost of removing

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