SHUTTERS FOR AERIAL PHOTOGRAPHY

BY
FREDERICK W. LUTZ, VICE-PRESIDENT
AND IRVING W. DOYLE, RESEARCH ENGINEER,
FAIRCHILD AERIAL CAMERA CORPORATION

IT IS THE INTENTION OF THIS ARTICLE TO PRESENT A REVIEW OF THE FIELD OF AERIAL CAMERA SHUTTERS PAYING PARTICULAR ATTENTION TO THE REQUIREMENTS OF PHOTOGRAMMETRY. A CONSIDERABLE AMOUNT OF RATHER ELEMENTARY MATERIAL IS INCLUDED FOR THE BENEFIT OF THOSE UNFAMILIAR WITH THE SUBJECT. A BRIEF DESCRIPTION OF EACH TYPE IS GIVEN TOGETHER WITH DATA ON THE PERFORMANCE TO BE EXPECTED FROM EACH.

IN THE COMPARATIVELY FEW YEARS SINCE THE ADVENT OF AERIAL PHOTOGRAPHY, THE ART HAS ADVANCED FROM THE MERE TAKING OF AERIAL PHOTOGRAPHS TO FIND ITS ULTIMATE PERFECTION IN THE HIGHLY EXACT SCIENCE OF PHOTOGRAMMETRY. NATURALLY THE DEVELOPMENT OF PRECISION EQUIPMENT HAS BEEN SIMULTANEOUS WITH THIS EVOLUTION OF THE FIELD. EACH COMPONENT PART HAS HAD TO BE CONTINUALLY IMPROVED THEREBY OPENING UP NEW FIELDS OF USE AND BY THE SAME ACT OUTMODING ITSELF AGAIN AND DEMANDING EVEN MORE IMPROVEMENTS. PARTICULARLY IS THIS TRUE WITH SHUTTERS.

REQUIREMENTS OF A GOOD SHUTTER

FOR TODAY'S USE, THE REQUIREMENTS OF A GOOD SHUTTER ARE NECESSARILY COMPLICATED BY THE FACT THAT THERE ARE SO MANY DIFFERENT USES. IN DETAIL, THE REQUIREMENTS ARE AS FOLLOWS:

SPEED RANGE: THE LOWER END OF THE SPEED RANGE IS PRACTICALLY LIMITED BY THE AMOUNT OF PERMISSIBLE MOTION OF THE IMAGE. THIS IS OF COURSE AFFECTED BY THE PLANE'S VELOCITY, ALTITUDE, CAMERA FOCAL LENGTH, VIBRATION CONSIDERATIONS, AND THE USE TO WHICH THE PICTURE IS TO BE PUT. MOST EXPERTS PLACE THIS SPEED AT 1/40 TO 1/50 OF A SECOND. THE HIGH SPEED END IS OF COURSE LIMITED BY THE AMOUNT OF LIGHT AND THE SPEED OF THE PHOTOGRAPHIC EMULSION. FOR LONG RANGE TELEPHOTO OBLIQUES IN GOOD LIGHT, IT MAY BE NECESSARY AND POSSIBLE TO USE SPEEDS AS HIGH AS 1/350 OF A SECOND. HOWEVER, FOR PHOTOGRAMMETRIC PURPOSES, SHORT FOCUS WIDE ANGLE LENSES USED AT HIGH ALTITUDES COMBINE TO PLACE THE PRACTICAL HIGH SPEED END FOR THIS USE AT 1/200 TO 1/250 OF A SECOND.

EFFICIENCY: THE SHUTTER EFFICIENCY, I. E., THE RATIO OF THE ACTUAL QUANTITY OF LIGHT ADMITTED DURING THE EXPOSURE TO THE QUANTITY WHICH WOULD HAVE BEEN ADMITTED HAD THE SHUTTER OPENED AND CLOSED AT INFINITE VELOCITY, SHOULD BE AS NEAR 100% AS POSSIBLE IN ALL CASES. PARTICULARLY IS THIS DESIRABLE FOR PHOTOGRAMMETRY AND PARTICULARLY AT THE LOW SPEED END OF THE RANGE IN ORDER TO KEEP THESE LOW SPEEDS AS HIGH AS POSSIBLE EVEN IN POOR LIGHT.

UNIFORMITY: THE EXPOSURE SHOULD BE UNIFORM OVER THE ENTIRE PICTURE AREA AND FURTHERMORE SHOULD BE SIMULTANEOUS OVER THE ENTIRE PICTURE AREA. THIS LAST POINT IS PARTICULARLY IMPORTANT IN THE FIELD OF PHOTOGRAMMETRY FOR SHOULD THE EXPOSURE BE LATER AT ONE PART OF THE PICTURE THAN AT ANOTHER, RELATIVE MOTION OF THE IMAGE, WHATEVER THE CAUSE, WOULD RESULT IN A DISTORTION OF THE PICTURE. IN CERTAIN ROUGH OBLIQUE VIEWS, THIS CONSIDERATION IS NOT IMPORTANT, HOWEVER.

RELIABILITY: THE EXTREME CONDITIONS MET WITH IN AERIAL PHOTOGRAPHY AND THE EXPENSE INVOLVED BY ANY FAILURES STRESS THE IMPORTANCE OF RELIABILITY. TEMPERATURES MAY RANGE FROM 40°F. BELOW ZERO TO 120°F. ABOVE ZERO AND HUMIDITY, SALT CORROSION, ABUSE, ETC. ARE FAR MORE TROUBLESOME HERE THAN IN ANY OTHER FIELD. IN CONNECTION WITH THIS POINT, IT HAS BEEN FOUND ADVISABLE TO KEEP THE DESIGN AS SIMPLE AS POSSIBLE AND ALSO PROVIDE FOR EASE OF ACCESS IN ORDER TO MAKE REPAIRS, ADJUSTMENTS, ETC.

CONSIDERATION OF THE DIFFERENT TYPES AVAILABLE

SHUTTERS ARE OF TWO GENERAL KINDS, THOSE OPERATING CLOSE TO THE FOCAL PLANE AND THOSE OPERATING AT OR NEAR THE OPTICAL CENTRE OF THE LENS.

FOCAL PLANE TYPE: THE SO-CALLED FOCAL PLANE TYPE OF SHUTTER IS RAPID-

LY DISAPPEARING FROM THE FIELD OF AERIAL PHOTOGRAPHY. IT HAS ONE GREAT DISADVANTAGE; IT DOES NOT SIMULTANEOUSLY EXPOSE THE WHOLE PICTURE AREA. THIS FACT ALONE RENDERS IT UNSUITABLE FOR PHOTOGRAMMETRY AND LIMITS ITS AERIAL PHOTOGRAPHIC USE TO OBLIQUES. AS USUALLY BUILT, IT CONSISTS OF AN OPAQUE FABRIC CURTAIN SITUATED AS CLOSE TO THE FOCAL PLANE AS PRACTICAL AND CARRIED ON ROLLERS. THIS CURTAIN HAS A SLIT AND AT THE TIME OF EXPOSURE THE CURTAIN UNROLLS FROM ONE ROLLER AND ROLLS UP ONTO THE OTHER CARRYING THE SLIT ACROSS THE PICTURE AREA EXPOSING EACH PART OF THE P'CTURE AS IT PASSES. IN SOME CASES, TWO CURTAINS ARE USED, ONE FORMING THE LEADING OR UNCOVERING EDGE OF THE SLIT AND THE OTHER FORMING THE TRAILING OR COVERING EDGE. ACCELERATION USUALLY CAUSES TAPERED EXPOSURE GIVING SHORTER EXPOSURE TO THE LAST PART WHERE THE CURTAIN HAS A HIGHER VELOCITY. IN THE TWO-CURTAIN TYPE, THE SLIT WIDTH OFTEN CHANGES IN SIZE DURING EXPOSURE FURTHER AFFECTING THE TAPER OF EXPOSURE. THE MOST SATISFACTORY FOCAL PLANE SHUTTER HAS BEEN ONE WITH A SINGLE CURTAIN, A FIXED SLIT WIDTH, AND A RETARD MECHANISM TO MAINTAIN CONSTANT VELOCITY WHILE TRAVELLING ACROSS THE PICTURE AREA. FOCAL PLANE SHUTTERS HAVE ONE DISTINCT ADVANTAGE: BY MAKING THE SLIT VERY NARROW, EXTREMELY SHORT EXPOSURES ARE POSSIBLE. SPEEDS OF 1/50 OF A SECOND TO 1/225 OF A SECOND HAVE BEEN USED FOR AERIAL PHOTOGRAPHY AT AN EFFICIENCY OF BETTER THAN 90%, WHILE 1/1000 OF A SECOND IS COMMON FOR SOME CAMERAS.

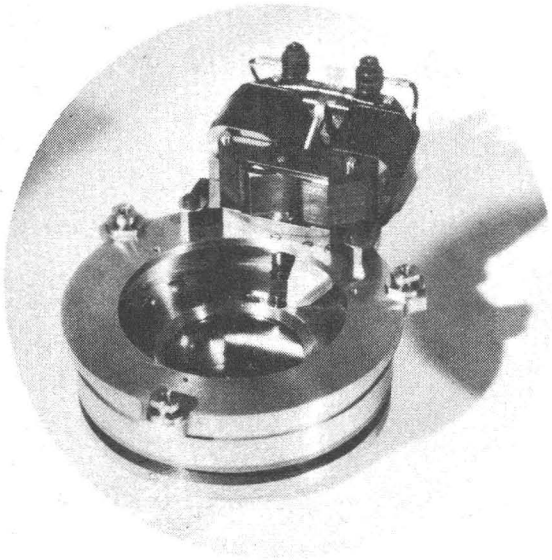
SOME YEARS AGO AN ATTEMPT WAS MADE TO REMEDY THE OBVIOUS FAULT OF NON-SIMULTANEOUS EXPOSURE IN FOCAL PLANE SHUTTERS BY CONSTRUCTING A SHUTTER OF RECTANGULAR LEAVES OF SHEET METAL ARRANGED AS IN A VENETIAN BLIND. THESE WERE CAUSED TO ROTATE AND MOVE LATERALLY AT THE SAME TIME. IT WAS QUICKLY DISCARDED, HOWEVER, AS IT WAS FOUND TO HAVE A VERY LOW EFFICIENCY AND BE INCAPABLE OF THE HIGH SPEED ADVANTAGES OF THE CURTAIN TYPE.

SHUTTERS OPERATING AT OR NEAR THE OPTICAL CENTRE OF THE LENS

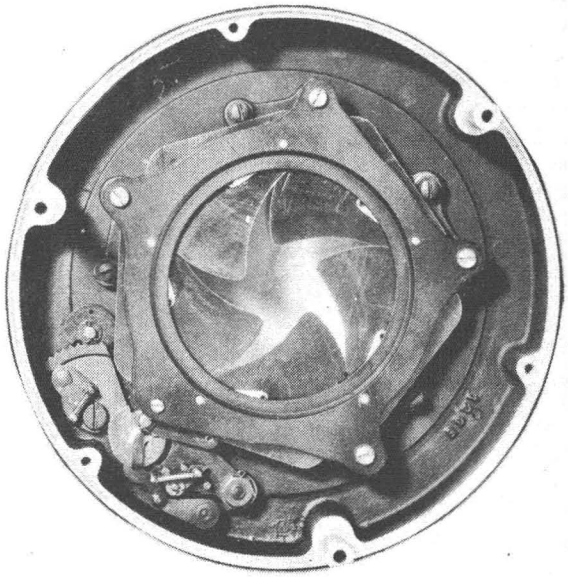
THERE ARE SEVERAL TYPES OF SHUTTERS OPERATING AT OR NEAR THE OPTICAL CENTRE OF THE LENS. DEVELOPMENT OF THIS TYPE HAS RECEIVED CONSIDERABLY MORE ENERGY THAN THE FOCAL PLANE TYPE BECAUSE RAYS DESTINED FOR ALL POINTS OF THE PLATE ARE SUPERIMPOSED AT THIS POINT AND HENCE ANY SHUTTER INSERTED HERE AUTOMATICALLY FULFILLS THE IMPORTANT REQUIREMENTS OF SUBSTANTIALLY SIMULTANEOUS EXPOSURE OF ALL PARTS OF THE PLATE. THE MOST COMMON TYPE CONSISTS OF A NUMBER OF BLADES WHICH ROTATE OR OSCILLATE ABOUT AN AXIS NORMAL TO THEIR PLANE, AND SINCE IT IS USUALLY MOUNTED BETWEEN THE FRONT AND REAR LENS ELEMENT ASSEMBLIES OF A CONVENTIONAL LENS, IT HAS ASSUMED THE NAME OF "BETWEEN-THE-LENS SHUTTER." IT IS MADE IN TWO GENERAL FORMS, ONE IN WHICH THE BLADES ROTATE COMPLETELY AROUND THEIR PIVOTS, COMING TO REST AGAIN IN SUBSTANTIALLY THE SAME POSITION AFTER EACH EXPOSURE, THE OTHER IN WHICH THE BLADES STOP AFTER UNCOVERING THE APERTURE AND REVERSE TO CLOSE THE APERTURE AGAIN. THE SPEED OR EXPOSURE IS ADJUSTED IN BOTH TYPES BY EITHER OR A COMBINATION OF TWO WAYS: BY VARYING THE SPRING TENSION OR MORE PREFERABLY BY SLOWING UP THE BLADES AFTER THEY HAVE OPENED AND BEFORE THEY BEGIN TO CLOSE AGAIN. THIS LATTER METHOD RESULTS IN THE HIGHEST POSSIBLE EFFICIENCY AT ALL SPEEDS. FROM A THEORETICAL ANALYSIS, IT IS APPARENT THAT THE SHUTTER EFFICIENCY IS DEPENDENT ON THE EFFICIENCY OF OPENING AND CLOSING AND THE RATIO OF FULL-OPEN TIME TO OPENING AND CLOSING TIME. SINCE THE LEAVES MUST BE ACCELERATED FROM STANDSTILL, THEY SHOULD BE AS SMALL AS POSSIBLE TO KEEP INERTIA AT A MINIMUM. THE NUMBER AND GEOMETRICAL SHAPE OF THE LEAVES ALSO AFFECTS OPENING AND CLOSING EFFICIENCY, VARYING IT FROM .33 TO .67 WITH CONSTANT VELOCITY. FOUR OR FIVE LEAVES OF A SECTOR SHAPE WITH CURVED SIDES, (A COMBINATION THAT GIVES A DISTORTED STAR-SHAPED OPENING WIDENING TO A CIRCLE) GIVES HIGHEST PRACTICAL OPENING AND CLOSING EFFICIENCY AS THIS UNCOVERS THE MAXIMUM AREA IN THE SHORTEST TIME, AND HAS THE LEAST INERTIA.

SEVERAL SHUTTERS HAVE BEEN BUILT WITH BLADES WHICH ROTATE 360° OR MORE. THESE SHUTTERS, HOWEVER, HAVE TO BE FAIRLY LARGE IN DIAMETER TO PROVIDE CLEARANCE FOR THE BLADES. THE CARL ZEISS COMPANY PRODUCES ONE OF THIS TYPE BUT WITH THE BLADES CURVED. THIS MODIFICATION REDUCES THE DIAMETER SOMEWHAT BUT NECESSITATES GREATER SPACING BETWEEN LENS ELEMENTS, THUS HAMPERING THE LENS MANUFACTURER. THE SHUTTER HAS GOOD EFFICIENCY CHARACTERISTICS GIVING 86.7% IN ONE MODEL AT A SPEED OF 1/100 OF A SECOND. THERE ARE FOUR BLADES

OF THE SHAPE DESCRIBED ABOVE. THE BLADES ARE MOVED BY PINIONS AT THEIR CENTRE OF ROTATION. SPEEDS UP TO 1/250 OF A SECOND ARE POSSIBLE WITH GOOD EFFICIENCY.



ELECTRIC SHUTTERS IN U. S. COAST AND GEODETIC SURVEY 9-LENS AERIAL CAMERA

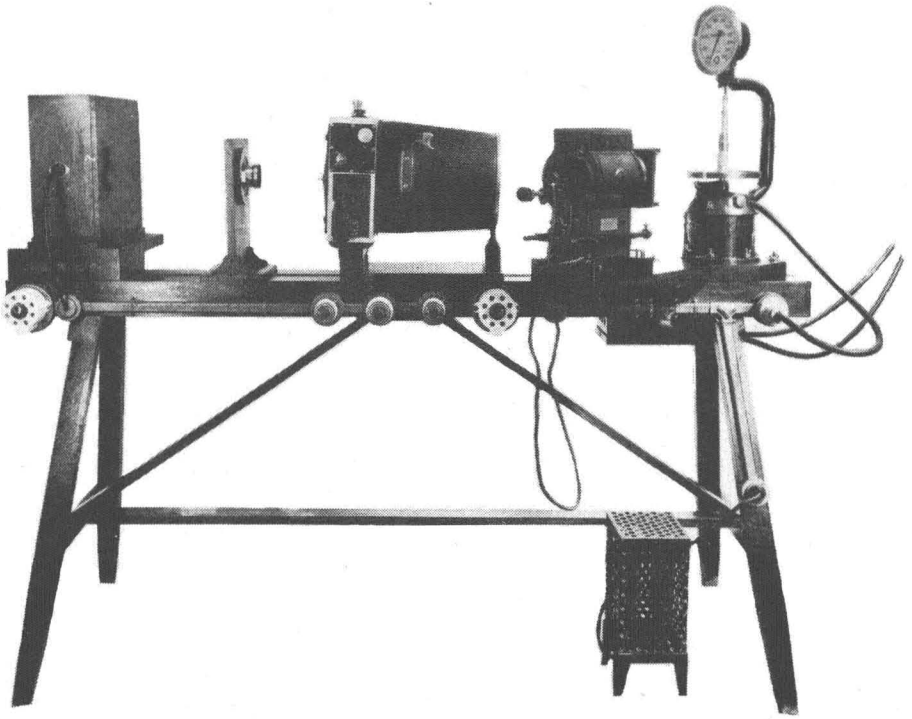


A FAIRCHILD REVERSING BLADE BETWEEN-THE-LENS SHUTTER WITH COVER REMOVED

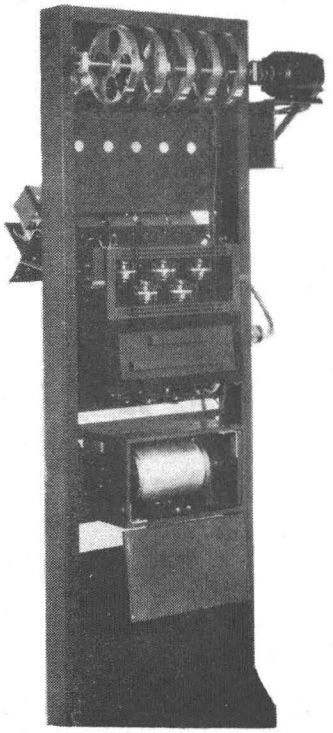
IN THE UNITED STATES, THE FAIRCHILD AERIAL CAMERA CORPORATION HAS PRODUCED REVERSING-BLADE TYPE SHUTTERS OF HIGH EFFICIENCY. THEY HAVE BEEN MADE IN SEVERAL SIZES AND HAVE THE DISTINCT ADVANTAGE OF CONSIDERABLY SMALLER DIAMETER FOR A GIVEN APERTURE SIZE THAN THE CONTINUOUS ROTATING TYPE, THUS PERMITTING SMALLER LENS CONE DESIGN AND CONSEQUENT SAVING IN WEIGHT, SPACE, WIND RESISTANCE, ETC. THESE SHUTTERS HAVE FIVE LEAVES OF A GEOMETRICAL SHAPE GIVING A STAR-SHAPED OPENING AS DESCRIBED ABOVE. THEY ATTAIN THEIR HIGH OPENING AND CLOSING EFFICIENCY BY ALLOWING A SMALL OVERLAP OF THE LEAVES, TO ALLOW ACCELERATION TO HIGH VELOCITY BEFORE ACTUALLY STARTING TO UNCOVER THE APERTURE AND THEN TRAVELLING SLIGHTLY BEYOND THE APERTURE TO GIVE THE SAME START ON CLOSING. THE DRIVING FORCE IS A SPRING AND IS TRANSMITTED TO THE LEAVES THROUGH A CRANK WHICH GIVES A HIGH VELOCITY WHILE ACTUALLY UNCOVERING OR COVERING THE APERTURE, AT THE SAME TIME ACCELERATING AND RETARDING THE LEAVES GENTLY. TESTS OF A SHUTTER HAVING A 2-1/2" APERTURE SHOW EFFICIENCIES OF 93.0% AT 1/50 OF A SECOND EXPOSURE; 86.0% AT 1/100 OF A SECOND AND 80.6% AT 1/150 OF A SECOND. THE SHUTTER IS EXTREMELY SIMPLE, HAVING A MINIMUM OF MOVING PARTS AND KEEPING ALL FORCES IN ONE PLANE, THIS BEING LARGELY RESPONSIBLE FOR ITS EXTREMELY TROUBLE-FREE PERFORMANCE EVEN AT SPEEDS OF 1/200 TO 1/250 OF A SECOND. SPEED CONTROL IS BY MEANS OF A RETARD OF THE INERTIA-ESCAPEMENT TYPE WHICH TAKES EFFECT AFTER THE LEAVES ARE FULLY OPEN AND RELEASES BEFORE THE LEAVES BEGIN TO CLOSE.

REVERSING BLADE SHUTTERS HAVE ALSO BEEN BUILT BY FAIRCHILD OPERATED BY A HIGH-SPEED ELECTROMAGNET. THIS WAS DONE FOR THE PURPOSE OF MAINTAINING SYNCHRONISM BETWEEN SHUTTERS IN MULTIPLE LENS CAMERAS. SHUTTERS OF THE U. S. COAST AND GEODETIC SURVEY 9-LENS CAMERA ARE OF THIS TYPE AND TESTS SHOW AN EFFICIENCY OF 92% AT 1/50 OF A SECOND AND 87% AT 1/80 OF A SECOND FOR SHUTTERS WITH AN APERTURE OF 1.7" (8-1/4" F4.5 LENS). THIS TYPE WAS ORIGINALLY DEVELOPED FOR USE WITH THE T3-A 5-LENS CAMERA. THE SHUTTERS ALL OPERATE ON A SINGLE TIMED CURRENT IMPULSE SUPPLIED BY A SPECIAL SURGE UNIT. SPEED IS CONTROLLED BY VARYING THE NATURAL FREQUENCY OF A TUNED CIRCUIT, THUS ADJUSTING THE DURATION OF THE SINGLE IMPULSE.

SHUTTERS HAVING FLAPPING BLADES HAVE ALSO BEEN BUILT TO OPERATE NEAR

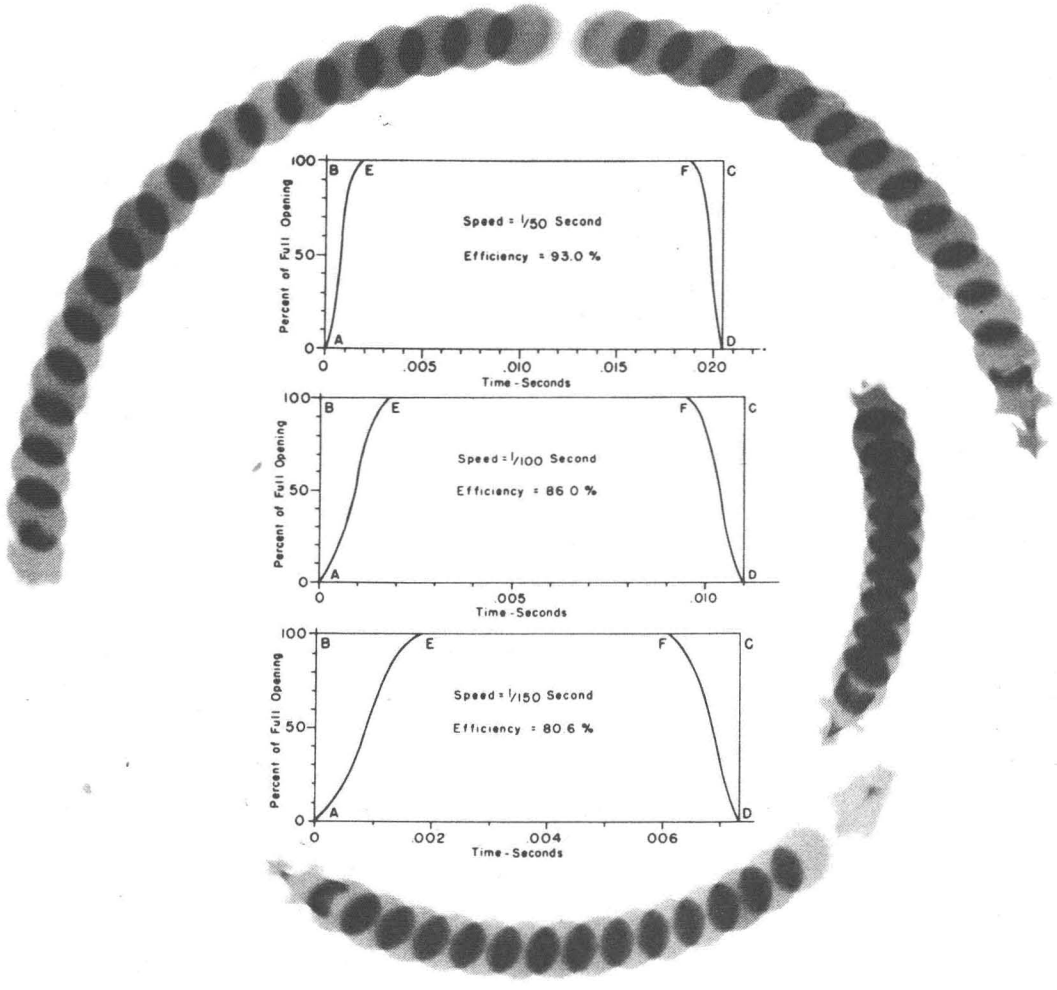


THE SPEED-TESTING MACHINE FOR TESTING BOTH FOCAL-PLANE AND BETWEEN-THE-LENS SHUTTERS



THE SPECIAL SPEED-TESTING MACHINE FOR TESTING MULTI-LENS SYNCHRONIZED ELECTRIC SHUTTERS

THE OPTICAL CENTRE. TWO FORMS ARE USED. IN THE MOST COMMON TYPE, THE BLADES ARE ARRANGED AS IN A VENETIAN BLIND. THE SHUTTER IS USUALLY MOUNTED IMMEDIATELY BEHIND THE REAR LENS ELEMENT. THE LEAVES ROTATE ABOUT AN AXIS IN THEIR OWN PLANE UNTIL THEY ARE PARALLEL TO THE PATH OF LIGHT, AND THEN BACK AGAIN. THIS TYPE IS PARTICULARLY ADAPTABLE TO LARGE APERTURES, 3", 4" AND 5" APERTURES HAVING BEEN SUCCESSFULLY BUILT AT SPEEDS UP TO 1/150 OF A SECOND. EFFICIENCY IS LOW BECAUSE EVEN WHEN FULLY OPENED, THE LIGHT TRANSMISSION IS ONLY OF THE ORDER OF 80% SINCE THE LEAVES REMAIN EDGEWISE IN THE PATH OF THE LIGHT. OVERALL EFFICIENCIES ON A 5" DIAMETER SHUTTER ARE 72% AT 1/50 OF A SECOND, 65% AT 1/100 OF A SECOND, AND 56% AT 1/150 OF A SECOND. IN THE OTHER TYPE, THE LEAVES ARE ARRANGED AS IN A FAN, BEING PIVOTED BETWEEN AN OUTSIDE RING AND A CENTRAL PIVOT BEARING MOUNTED ON FOUR STRUTS. BOTH ARRANGEMENTS ARE LIMITED TO NARROW ANGLE WORK. THEY ARE NOT ADAPTED TO PHOTOGRAMMETRY WORK BUT HAVE A DEFINITE USE FOR VERY LARGE APERTURE, NARROW ANGLE WORK AT MEDIUM SPEEDS.



SHUTTER TESTING MEANS

THERE ARE SEVERAL TYPES OF SHUTTER SPEED TESTING MACHINES. THE TYPE MOST GENERALLY USED TODAY FOR BOTH FOCAL PLANE AND BETWEEN-THE-LENS SHUTTERS IS A MODIFICATION OF THE NUTTING DESIGN. AN ARC LIGHT SHINES ON A REVOLVING DRUM WITH 60 MIRROR FACES ON ITS SURFACE. THE BEAMS FROM THE MIRRORS SWEEP ACROSS THE SHUTTER TO BE TESTED, EACH BEAM ILLUMINATING IT. AS IT OPENS AND CLOSES, THE SUCCESSIVE BEAMS PASS THROUGH AND ARE FOCUSED BY A LENS ONTO A DISC OF SENSITIZED PAPER MOUNTED ON A HOLDER ON THE SHAFT OF AN ELECTRIC MOTOR. THIS FORMS SUCCESSIVE IMAGES OF THE SHUTTER APERTURE ON THE DISC,

ONE FOR EACH SUCCESSIVE BEAM OR FLASH. THE MOTOR ROTATES THE SENSITIZED PAPER SO THAT EACH FLASHED IMAGE IS DISPLACED FROM THE PRECEDING ONE. THE MIRROR SPEED IS KNOWN AND SINCE THERE ARE 60 MIRRORS, THE FLASHING RATE IN FLASHES PER SECOND IS EXACTLY THE SAME AS THE MIRROR SPEED IN REVOLUTIONS PER MINUTE. FLASHING RATES AS HIGH AS 2400 PER SECOND ARE THUS EASILY OBTAINED. THE SHUTTER SPEED IS THEN FOUND DIRECTLY BY COUNTING THE NUMBER OF IMAGES ON THE TEST. THE EFFICIENCY IS FOUND AS FOLLOWS: THE AREA OF EACH IMAGE IS MEASURED WITH A PLANIMETER AND PLOTTED AGAINST THE CORRESPONDING TIME. THE AREA ENCLOSED BY THE CURVE SO FORMED AND THE BASE LINE IS MEASURED AND THE AREA OF THE RECTANGLE FORMED BY THE BASE, THE FULL-OPEN LINE AND THE VERTICALS AT THE EXTREMITIES ARE ALSO MEASURED. THE EFFICIENCY IS THE CURVED AREA DIVIDED BY THE RECTANGULAR AREA. A TEST OF A FAIRCHILD SHUTTER IS ILLUSTRATED IN FIGURE 1. AREA A E F D REPRESENTS THE ACTUAL LIGHT ADMITED. AREA A B C D REPRESENTS WHAT WOULD HAVE BEEN ADMITTED HAD THE SHUTTER OPENED AND CLOSED AT INFINITE VELOCITY. THE EFFICIENCY IS AREA A E F D DIVIDED BY AREA A B C D.

FOR TESTING MULTI-LENS SYNCHRONIZED ELECTRIC SHUTTERS, A SPECIAL MODIFICATION OF THE ABOVE MACHINE WAS BUILT. FIVE INCANDESCENT LAMPS ARE USED AND FIVE MIRROR DRUMS MOUNTED ON A SINGLE SHAFT ROTATED BY A SYNCHRONOUS MOTOR. THE SHUTTERS ARE MOUNTED IN A BOX IN THEIR ACTUAL POSITION (HORIZONTALLY). FIVE LENSES BRING THE IMAGES TO FOCUS ON A REVOLVING DRUM CARRYING THE SENSITIZED PAPER SO THAT AS THE SHUTTERS ARE TRIPPED, THE FIVE TESTS APPEAR SIDE BY SIDE. ANY LACK OF SYNCHRONISM IS THEREFORE IMMEDIATELY SHOWN UP. ALL FIVE SHUTTERS ACTUALLY OPERATE TOGETHER WITHIN 1/1000 OF A SECOND. IN THIS MACHINE, THE SHUTTER BOX IS SO CONSTRUCTED AND INSULATED THAT THE INSIDE MAY BE BROUGHT DOWN TO EXTREMELY LOW TEMPERATURES AND THE SHUTTERS THEN TESTED, THE LIGHT BEAMS PASSING THROUGH PLATE GLASS WINDOWS IN THE BOX.

RECTANGULAR COORDINATES AND STANDARD HORIZONTAL DATUM

BY

R. M. WILSON, U. S. GEOLOGICAL SURVEY

PLANE RECTANGULAR COORDINATE SYSTEMS TO REPRESENT STANDARD DATUM, WHICH MAY BE EXTENDED OVER LARGE AREAS WITHOUT EXCESSIVE LOSS OF ACCURACY, HAVE ONLY RECENTLY BEEN DEVISED FOR USE IN THE UNITED STATES. IN ORDER THAT INDIVIDUAL SYSTEMS MAY BE STATE-WIDE WITHOUT INTRODUCING OBJECTIONABLE DISTORTION THEY MUST BE PLANNED CAREFULLY AND MUST HAVE THEIR FOUNDATIONS LAID IN EXACT MATHEMATICS. THE UNITED STATES COAST AND GEODETIC SURVEY, IN CERTAIN OF ITS PUBLICATIONS SETS FORTH THE THEORY OF THESE PLANE COORDINATE SYSTEMS AND BY NUMERICAL EXAMPLES ILLUSTRATES THE DIFFERENT COMPUTATIONS INVOLVED. IT IS NOT INTENDED HERE TO OUTLINE THE THEORY AGAIN, NOR TO PROVIDE A DETAILED GUIDE TO THE USE OF THE SYSTEMS. ONE URGENT PURPOSE IT IS HOPED THAT THEY WILL SERVE IS TO WELD TOGETHER UPON A COMMON HORIZONTAL DATUM MANY OF THE VARIOUS INDIVIDUAL LOCAL SURVEYS CONDUCTED BY ENGINEERS IN ALL BRANCHES OF THE PROFESSION. WITH THIS PURPOSE IN MIND, IT IS INTENDED IN THE FOLLOWING PARAGRAPHS TO DISCUSS CERTAIN FEATURES OF THE SUBJECT, PERHAPS FROM A NEW POINT OF VIEW, WITHOUT THE DISTRACTION OF MATHEMATICAL DERIVATIONS.

THE STANDARD PLANE COORDINATE SYSTEMS MAY BE REGARDED AS PARTS OF THE FUNDAMENTAL WORLD-WIDE GEODETIC SYSTEM THAT HAVE BEEN TRANSLATED INTO A FORM MORE CONVENIENT FOR EVERYDAY USE. IN THE GEODETIC SYSTEM DISTANCES MEASURED ON THE GROUND ARE REDUCED TO SEA LEVEL IN ORDER THAT ALL PARTS OF A SURVEY MAY BE CONSIDERED AS LYING ON THE SURFACE OF THE GEODETIC REFERENCE SPHEROID. THIS ASSUMPTION, TAKEN FOR GRANTED IN THE FOLLOWING DISCUSSION, IMPLIES THAT THE PLANE COORDINATE SYSTEMS ARE ARRANGED ALSO SO AS TO RELATE DIRECTLY TO SEA LEVEL DISTANCES RATHER THAN TO DISTANCES MEASURED AT GROUND LEVEL.

NOW A TRUE RECTANGULAR COORDINATE SYSTEM MUST BE CONTAINED IN A PLANE: IT IS NOT POSSIBLE TO ARRANGE SUCH A SYSTEM SO THAT IT WILL BE FORM-FITTED TO THE CURVATURE OF THE EARTH OR OF THE REFERENCE SPHEROID. THE PROBLEM HERE, THEREFORE, AS IN MAPPING, IS TO TAKE THE DETAILS OF A SURVEY FROM THE