



IEEE Standard for General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers

IEEE Power & Energy Society

Sponsored by the
Transformers Committee

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IEEE Standard for General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers

Sponsor

Transformers Committee
of the
IEEE Power & Energy Society

Approved 17 June 2010

IEEE-SA Standards Board

Abstract: Electrical and mechanical requirements for liquid-immersed distribution and power transformers, and autotransformers and regulating transformers; single- and polyphase, with voltages of 601 V or higher in the highest voltage winding, are set forth. This standard is a basis for the establishment of performance, and limited electrical and mechanical interchangeability requirements of equipment are described; it is also a basis for assistance in the proper selection of such equipment. The requirements in this standard apply to all liquid-immersed distribution, power, and regulating transformers except the following: instrument transformers, step voltage and induction voltage regulators, arc furnace transformers, rectifier transformers, specialty transformers, grounding transformers, mobile transformers, and mine transformers.

Keywords: autotransformers, distribution transformers, electrical requirements, mechanical requirements, power transformers, regulating transformers

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Introduction

This introduction is not part of IEEE Std C57.12.00-2010, IEEE Standard for General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers.

This standard is a voluntary consensus standard. Its use may become mandatory only when required by a duly constituted legal authority or when specified in a contractual agreement. To meet specialized needs and to allow for innovation, specific changes are permissible when mutually determined by the user and the manufacturer, provided these changes do not violate existing laws and are considered technically adequate for the function intended.

When this standard is used on a mandatory basis, the words *shall* and *must* indicate mandatory requirements. The words *should* and *may* refer to matters that are recommended or permissible, but not mandatory.

When applicable, editorial changes have been incorporated into this revision. Sentence structure and punctuation have been edited to improve clarity and conciseness. Also, editorial changes have been made to conform to the *2009 IEEE Standards Style Manual*.^a Some changes have also been made to correct errors in previous revisions. When applicable, references to other standards have been updated.

A summary of the major changes is listed here, in sequential order.

- a) Editorial changes were made to the Scope, and a Purpose was added.
- b) Old Table 4 through Table 9 and related Notes have been deleted.
- c) New Table 4, Table 5, and Table 6 have been added.
- d) Subclause 5.10, second sentence, has been revised to read "...shall be its *maximum system voltage* and basic lightning impulse insulation level (BIL)."
- e) Former 5.10.1.3 is now 5.10.1 and was revised. The old table for front-of-wave insulation levels was not included in the 2006 version of this standard. This table has been included as Annex A in this 2010 version of the standard, for historical purposes.
- f) Former 5.10.2.4 is now 5.10.3.4 and has been revised to read: "In any case, the insulation level of the neutral bushing shall be equal or greater than the specified insulation level of the neutral end of the winding."
- g) Former 5.10.2.5 is now 5.10.3.5 has been revised to read: "Insulation levels shall not be assigned where the neutral end of the winding is not brought out of the tank through a bushing and is solidly grounded to the tank."
- h) Former 5.10.3.3 has been deleted.
- i) Former 5.10.4 and 5.10.5 have been combined into one new subclause 5.10.5.
- j) Subclauses 5.10.7.1 and 5.10.7.2 have been revised.
- k) Subclause 5.11.3 is new, along with Figure 3.
- l) Former Table 10 is now Table 7, and several Notes were changed.
- m) A new introduction has been added to 7.1.3.
- n) The X0/X1 ratio was changed from "2.0" to "1.0" in 7.1.5.3.
- o) Former Table 21 has been replaced with a new Table 18.

^a The *IEEE Standards Style Manual* is available at <http://standards.ieee.org/guides/style/>.

- p) Subclause 8.6 has been added, and the old 8.6 has been renumbered as 8.7.
- q) Annex A has been added; and the old Annex A (Bibliography) has been changed to Annex B.

Revisions of individual clauses (now modified) were prepared by separate groups within the Transformers Committee. Those clauses were balloted independently according to applicable rules and procedures of the IEEE for the preparation and approval of voluntary consensus standards. This process was approved by the IEEE Transformers Committee, the IEEE-SA Standards Board, and the Accredited Standards Committee for Distribution and Power Transformers and Regulators (C57). Applicable rules and procedures; specifically procedures for voting, review, and attempted reconciliation of dissenting viewpoints; a 60-day public review period; and final review and approval by the ANSI Board of Standards Review, were followed.

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IEEE Standard for ~~Standard~~ General Requirements for Liquid-Immersed Distribution, Power, and Regulating Transformers

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1. Overview

1.1 Scope

This standard ~~is a basis for the establishment of performance, limited interchangeability, and safety requirements of equipment described. It is also a basis for assistance in the proper selection of such equipment.~~ describes electrical and mechanical

~~This standard describes electrical, mechanical, and safety~~ requirements of liquid-immersed distribution and power transformers, and autotransformers and regulating transformers, single-phase and polyphase, with voltages of 601 V or higher in the highest voltage winding.

This standard applies to all liquid-immersed distribution, power, and regulating transformers that do not belong to the following types of apparatus:

- a) Instrument transformers
- b) Step voltage and induction voltage regulators
- c) Arc furnace transformers
- d) Rectifier transformers
- e) Specialty transformers
- f) Grounding transformers
- g) Mobile transformers
- h) Mine transformers

1.2 Purpose

This standard is used on a mandatory basis, for the words shall establishment of performance, and limited electrical and mechanical interchangeability requirements of the equipment are described. It is also a basis for assistance in the proper selection of such equipment.

1.3 Word usage

When this standard is used on a mandatory basis, the words *shall* and *must* indicate mandatory requirements. The words *should* and *may* refer to matters that are recommended or permissible, but not mandatory. The introduction of this voluntary consensus standard describes the circumstances under which the standard *may* be used on a mandatory basis.

2. Normative references

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

~~ANSI C92.2, American National Standard for power systems—Alternating current electrical systems and equipment operating at voltages above 230 kV nominal—Preferred voltage ratings.¹~~

~~ANSI C84.1, American National Standard Voltage Ratings~~ for Electric Power Systems and Equipment Voltage Ratings (60 Hz).¹

~~ANSI/CGA V-1, Compressed Gas Cylinder Valve Outlet and Inlet Connections.~~ ASME Boiler and Pressure Vessel Code (BPV).²

~~ASME B1.1, American National Standard for Unified Inch Screw Threads (UN and UNR Thread Form).~~

ASTM D92, Standard Test Methods for Flash and Fire Points by Cleveland Open Cup Tester.³

ASTM D1933, Standard Specification for Nitrogen Gas as an Electrical Insulating Material.

ASTM D2225, Standard Test Methods for Silicone Fluids Used for Electrical Insulation.

ASTM D3487, Standard Specification for Mineral Insulating Oil Used in Electrical Apparatus.

ASTM D5222, Standard Specification for High Fire-Point Mineral Electrical Insulating Oils.

~~IEEE Std 315TM, IEEE Graphic Symbols for Electrical and Electronics Diagrams (Including Reference Designation Letters).~~ CGA V-1, Compressed Gas Cylinder Valve Outlet and Inlet Connections.^{4,5}

~~IEEE Std 315ATM, IEEE Standard Graphic Symbols for Electrical and Electronics Diagrams (Supplement to IEEE Std 315-1975).~~

~~IEEE Std 469TM, IEEE Recommended Practice for Voice Frequency Electrical Noise Tests~~

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³ ASTM publications are available from the American Society for Testing and Materials, 100 Barr Harbor Drive, West Conshohocken, PA 19428-2959, USA (<http://www.astm.org/>).

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[IEEE Std 315TM, IEEE Standard Graphic Symbols for Electrical and Electronics Diagrams \(Including Reference Designation Letters\).](#)^{5, 6}

[IEEE Std 315ATM, Supplement to Graphic Symbols for Electrical and Electronics Diagrams \(Supplement to IEEE Std 315-1975\).](#)

[IEEE Std 469TM, IEEE Recommended Practice for Voice-Frequency Electrical-Noise Tests of Distribution Transformers.](#)

[IEEE Std C57.12.70TM, IEEE Standard Terminal Markings and Connections for Distribution and Power Transformers.](#)

IEEE Std C57.12.80TM, IEEE Standard Terminology for Power and Distribution Transformers.

IEEE Std C57.12.90TM, IEEE Standard Test Code for Liquid-Immersed Distribution, Power, and Regulating Transformers.⁷

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²ASME publications are available from the American Society of Mechanical Engineers, 3 Park Avenue, New York, NY 10016-5990, USA (<http://www.asme.org/>).

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IEEE Std C57.131TM, IEEE Standard Requirements for Load Tap Changers.

~~IEEE Std C62.11TM, IEEE Standard for Metal Oxide Surge Arresters for Alternating Current Power Circuits (>1 kV).~~

~~IEEE Std C62.22TM, IEEE Guide for the Application of Metal Oxide Surge Arresters for Alternating Current Systems.~~

3. Definitions

Standard transformer terminology available in IEEE Std C57.12.80 shall apply. ~~Other electrical terms are defined in⁸ The *Authoritative Dictionary of IEEE Standards Dictionary: Glossary of Terms & Definitions, Seventh Edition [B14].*⁷ should be referenced for other electrical terms.~~⁹

4. Service conditions

4.1 Usual service conditions

4.1.1 General

Transformers conforming to this standard shall be suitable for operation at rated kVA under the following usual service conditions.

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⁷ As this standard goes to press, IEEE Std C57.12.90-2010 is approved but not yet published. However, the draft, IEEE PC57.12.90/D14 (1 April 2010), is available from the IEEE. Anticipated publication date is September 2010. Contact the IEEE Standards Department at 1 (732) 562-3800 for status information.

⁸ Information on references can be found in Clause 2.

⁹ The IEEE Standards Dictionary: Glossary of Terms & Definitions is available at <http://shop.ieee.org/>.

4.1.2 Temperature

4.1.2.1 Cooling air temperature limit

When air-cooled, the temperature of the cooling air (ambient temperature) shall not exceed 40 °C, and the average temperature of the cooling air for any 24 h period shall not exceed 30 °C.

4.1.2.2 Liquid temperature limit

The top liquid temperature of the transformer (when operating) shall not be lower than –20 °C. Liquid temperatures below –20 °C are not considered as usual service conditions.

4.1.2.3 Cooling water temperature limit

When water-cooled, the temperature of the cooling water (ambient temperature) shall not exceed 30 °C, and the average temperature of the cooling water for any 24 h period shall not exceed 25 °C. Minimum water temperature shall not be lower than 1 °C, unless the cooling water includes antifreeze, which is suitable for –20 °C operation.

4.1.3 Altitude

The altitude shall not exceed 1000 m (3300 ft).

~~⁶ Information on references can be found in Clause 2.~~

~~⁷ The numbers in brackets correspond to those of the bibliography in Annex A.~~

4.1.4 Supply voltage

The supply-voltage wave shape shall be approximately sinusoidal. The phase voltages supplying a polyphase transformer shall be approximately equal in magnitude and time displacement.

4.1.5 Load current

The load current shall be approximately sinusoidal. The harmonic factor shall not exceed 0.05 per unit. Harmonic factor is defined in IEEE Std C57.12.80.

4.1.6 Operation above rated voltage or below rated frequency

4.1.6.1 Capability

Transformers shall be capable of the following:

- a) Operating continuously above rated voltage or below rated frequency, at maximum rated kVA for any tap, without exceeding the limits of observable temperature rise in accordance with 5.11.1.1 when all of the following conditions prevail:
 - 1) Secondary voltage and volts per hertz do not exceed 105% of rated values-
 - 2) Load power factor is 80% or higher
 - 3) Frequency is at least 95% of rated value
- b) Operating continuously above rated voltage or below rated frequency, on any tap at no load, without exceeding limits of observable temperature rise in accordance with 5.11.1, when neither the voltage nor volts per hertz exceed 110% of rated values.

For multi-winding transformers or autotransformers, 4.1.6.1 applies only to specific loading conditions used as the basis of design. These loading conditions involve simultaneous coordination of kVA input and output, load power factors, and winding voltage combinations [see item j) of 4.3.3]. Differences in loading and voltage regulation for various output windings may prevent simultaneous achievement of 105% voltage on all output terminals. In no case shall the kVA outputs specified for any loading condition require continuous loading of any input winding in excess of its rating.

4.1.6.2 Maximum continuous transformer operating voltage

The maximum continuous transformer operating voltage should not exceed the levels specified in ANSI C84.1. System conditions may require voltage transformation ratios involving tap voltages higher than the maximum system voltage for regulation purposes. However, the appropriate maximum system voltage should be observed under operating conditions.

4.1.7 Outdoor operation

Unless otherwise specified, transformers shall be suitable for outdoor operation.

4.1.8 Step-down operation

Unless otherwise specified, transformers shall be designed for step-down operation.

4.1.8.1 Generator step-up transformers

Transformers identified as generator step-up transformers shall be designed for step-up operation.

4.1.8.2 System tie ~~auto~~transformers

Transformers identified as system tie transformers or autotransformers shall be designed for step-down operation, or step-up operation, or both, as specified by the user.

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4.1.9 Tank or enclosure finish

Temperature limits and tests shall be based on the use of a nonmetallic pigment surface paint finish. It should be noted that metallic-flake paints, such as aluminum and zinc, have properties that increase the temperature rise of transformers, except in direct sunlight.

4.2 Loading at other-than-rated conditions

IEEE Std C57.91-~~1995~~TM [B28] provides guidance for loading at other-than-rated conditions including [the following](#).¹⁰

¹⁰ [The numbers in brackets correspond to those of the bibliography in Annex B.](#)

- a) Ambient temperatures higher or lower than the basis of rating-
- b) Short-time loading in excess of nameplate kVA with normal life expectancy
- c) Loading that results in reduced life expectancy

IEEE Std C57.91-~~1995~~ [B28] is [an IEEE guide, and as such, it does](#) not ~~standard-specify mandatory requirements~~. It provides the best known general information for loading of transformers under various conditions based on typical winding insulation systems. It is based upon the best engineering information available at the time of preparation. The guide discusses limitations of ancillary components other than windings that may limit the capability of transformers. When specified, ancillary components and other construction features (such as cables, bushings, tap changers, oil expansion space, etc.) shall be supplied in a manner that will not limit the loading to less than the capability of the windings.

4.3 Unusual service conditions

Conditions other than those described in 4.1 are considered unusual service conditions and, when prevalent, should be brought to the attention of those responsible for the design and application of the apparatus. Examples of some of these conditions are listed in 4.3.3.

4.3.1 Unusual temperature and altitude conditions

Transformers may be used at higher or lower ambient temperatures or at higher altitudes than those specified in 4.1.3, but special consideration should be given to these applications. IEEE Std C57.91-~~1995~~ [B28] provides information on recommended practices.

4.3.2 Insulation at high altitude

The dielectric strength of transformers that depend in whole or partly upon air for insulation decreases as the altitude increases due to the effect of decreased air density. When specified, transformers shall be designed with larger air spacing between terminals using the correction factors of Table 1 to obtain adequate air dielectric strength at altitudes above 1000 m (3300 ft).

4.3.2.1 Insulation level

The minimum insulation necessary at the required altitude can be obtained by dividing the standard insulation level at 1000 m (3300 ft) by the appropriate correction factor from Table 1.¹¹

4.3.2.2 Bushings

Bushings with additional length or arcing distance shall be furnished when necessary for operation above 1000 m (3300 ft).

¹¹ Notes in text, tables, and figures of a standard are given for information only and do not contain requirements needed to implement this standard.

**Table 1—Dielectric strength correction factors
for altitudes greater than 1000 m (3300 ft)**

Altitude m/(ft)	Altitude correction factor for dielectric strength
1000/(3300)	1.00
1200/(4000)	0.98
1500/(5000)	0.95
1800/(6000)	0.92
2100/(7000)	0.89
2400/(8000)	0.86
2700/(9000)	0.83
3000/(10 000)	0.80
3600/(12 000)	0.75
4200/(14 000)	0.70
4500/(15 000)	0.67
<u>NOTE—An altitude of 4500 m (15 000 ft) is considered a maximum for transformers conforming to this standard.</u>	

4.3.3 Other unusual service conditions

Other unusual service conditions include the following:

- Damaging fumes or vapors, excessive or abrasive dust, explosive mixtures of dust or gases, steam, salt spray, excessive moisture, or dripping water, etc.
- Abnormal vibration, tilting, shock, or seismic conditions.
- Ambient temperatures outside of normal range.
- Unusual transportation or storage conditions.
- Unusual space limitations.
- Unusual maintenance problems.

- g) Unusual duty or frequency of operation, or high-current short-duration loading.
- h) Unbalanced ac voltages, or departure of ac system voltages from a substantially sinusoidal wave form.
- i) Loads involving abnormal harmonic currents such as those that may result where appreciable load currents are controlled by solid-state or similar devices. Such harmonic currents may cause excessive losses and abnormal heating.
- j) Specified loading conditions (kVA outputs, winding load power factors, and winding voltages) associated with multi winding transformers or autotransformers.
- k) Excitation exceeding either 110% rated voltage or 110% rated volts per hertz.
- l) Planned short circuits as a part of regular operating or relaying practice.
- m) Unusual short-circuit application conditions differing from those described as usual in Clause 7.
- n) Unusual voltage conditions (transient overvoltages, resonance, switching surges, etc) may require special consideration in insulation design.
- o) Unusually strong magnetic fields. It should be noted that solar magnetic disturbances may result in the flow of telluric currents in transformer neutrals.
- p) Large transformers with high-current isolated-phase bus ducts. It should be noted that high-current isolated-phase bus ducts with strong magnetic fields may cause unanticipated circulating currents in transformer tanks and covers, and in bus ducts. Losses resulting from these unanticipated currents may result in excessive temperatures when corrective measures are not included in the design.
- q) Parallel operation. It should be noted that while parallel operation is not unusual, it is desirable that users advise the manufacturer when paralleling with other transformers is planned and identify the transformers involved.

~~⁸Notes in text, tables, and figures are given for information only and do not contain requirements needed to implement the standard.~~

5. Rating data

5.1 Cooling classes of transformers

Transformers shall be identified according to the cooling method employed. For liquid-immersed transformers, this identification is expressed by a four-letter code described as follows. These designations are consistent with IEC 60076-2: 1993 [B12].

First letter: Internal cooling medium in contact with the windings:

- O Mineral oil or synthetic insulating liquid with fire point $\geq 300\text{ }^{\circ}\text{C}$ ¹²
- K Insulating liquid with fire point $> 300\text{ }^{\circ}\text{C}$
- L Insulating liquid with no measurable fire point

Second letter: Circulation mechanism for internal cooling medium:

- N Natural convection flow through cooling equipment and in windings
- F Forced circulation through cooling equipment (i.e., coolant pumps), natural convection flow in windings (also called *non-directed flow*)
- D Forced circulation through cooling equipment, directed from the cooling equipment into at least the main windings

Third letter: External cooling medium:

A Air

W Water

Fourth letter: Circulation mechanism for external cooling medium:

N Natural convection

¹² *Fire point:* The lowest temperature at which a specimen will sustain burning for 5 s- (ASTM D92-~~1998~~, “Cleveland Open Cup” test method).

F Forced circulation [fans (air cooling), pumps (water cooling)]

NOTE 1—In a transformer with forced, non-directed cooling (second code letter F), the rates of coolant flow through all the windings vary with the loading, and are not directly controlled by the pumps. The pumped oil flows freely inside the tank and is not forced to flow through the windings.

NOTE 2—In a transformer designated as having forced directed coolant circulation (second code letter D), the rate of coolant flow through the main windings is determined by the pumps and not by the loading. A minor fraction of the coolant flow through the cooling equipment may be directed outside the main windings to provide cooling for core and other parts. Regulating windings and/or other windings having relatively low power may also have non-directed coolant circulation.

A transformer may be specified with more than one kVA rating (also referred to as *cooling stages*). The transformer nameplate shall list the rated kVA and cooling class designation for each rating. The ratings shall be listed in order of increasing kVA. The cooling class designations are normally listed in order with a diagonal slash separating each one.

Examples:

ONAN/ONAF. The transformer has a set of fans that may be put in service as desired at high loading. The coolant circulation is by natural convection only.

ONAN/OFAF. The coolant circulation is by natural convection only at base loading. However, the transformer has cooling equipment with pumps and fans to increase the power-carrying capacity at high loading.

Examples of the cooling class designations used in IEEE Std C57.12.00-~~1993~~[2006](#) and in previous revisions, and the corresponding new designations, are provided in Table 2.

Table 2—Cooling class designation

Present designations	Previous designations
ONAN	OA
ONAF	FA
ONAN/ONAF/ONAF	OA/FA/FA
ONAN/ONAF/OFAF	OA/FA/FOA
ONAN/OFAF	OA/FOA
ONAN/ODAF/ODAF	~~OA/FOA*/FOA*~~ OA/FOA

OFAF	FOA
OFWF	FOW
ODAF	FOA ^a
ODWF	FOW ^a

^a Indicates directed oil flow per ~~Table 9, Note preceding NOTE 2-above.~~

5.2 Frequency

Unless otherwise specified, transformers shall be designed for operation at a frequency of 60 Hz.

5.3 Phases

5.3.1 General

Transformers described in this standard are either single-phase or three-phase. Standard ratings are included in product standards for particular types of transformers. When specified, other phase arrangements may be provided.

5.3.2 Scott-connected or T-connected transformers

5.3.2.1 Phase transformation

These may be provided to accomplish three-phase to two-phase transformation, or vice versa, or to accomplish three-phase to three-phase transformation. Common arrangements used to accomplish such transformations are described here [in 5.3.2.2, 5.3.2.3, and 5.3.2.4.](#)

5.3.2.2 Dissimilar single-phase transformers

Two single-phase transformers are assembled in an enclosure, and permanently interconnected, with the following characteristics:

- Performance characteristics shall be based on bank operation of three-phase to two-phase transformation or vice versa.
- The single-phase transformers may not be identical or interchangeable.

5.3.2.3 Three-legged core

Another arrangement uses a three-legged core with main and teaser coil assemblies located on the two outer legs, and a center leg that has no coil assembly. This provides a common magnetic circuit for the two outer legs.

5.3.2.4 Identical single-phase transformers

When specified, two identical single-phase transformers shall be furnished.

- The kVA rating of each transformer shall be half the bank output required. The rating of the
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- b) Performance characteristics (except heating) shall be based on single-phase operation.
- c) The temperature rise shall be based on delivering the required bank capacity when transforming from three-phase to two-phase or from two-phase to three-phase, as specified.
- d) Transformers shall be interchangeable as main and teaser.
- e) Regulating taps are not usually supplied on transformers for three-phase to two-phase or from two-phase to three-phase service. When taps are required, the teaser tap shall be 86.6% of the mean regulating taps (used here, *mean* refers to the midpoint of the range of regulating taps).

5.4 Rated kilovoltamperes

5.4.1 General

The rated kVA of a transformer shall be the output that can be delivered for the time specified at rated secondary voltage and rated frequency without exceeding the specified temperature-rise limitations under prescribed conditions of test, and within the limits of established standards.

5.4.2 Preferred continuous kVA ratings

Preferred continuous kVA ratings of single-phase and three-phase distribution and power transformers are based on an average winding rise by resistance of 65 °C, in accordance with 5.11.1.1, and are listed in Table 3.

Table 3—Preferred continuous kilovoltampere ratings

Single-phase transformers	Three-phase transformers
5	15
10	30
15	45
25	75
37.5	112.5
50	150
75	225
100	300
167	500
250	750
333	1000
500	1500
—	2000
833	2500
1250	3750
1667	5000
2500	7500
3333	10 000
—	12 000
5000	15 000
6667	20 000
8333	25 000
10 000	30 000
12 500	37 500
16 667	50 000